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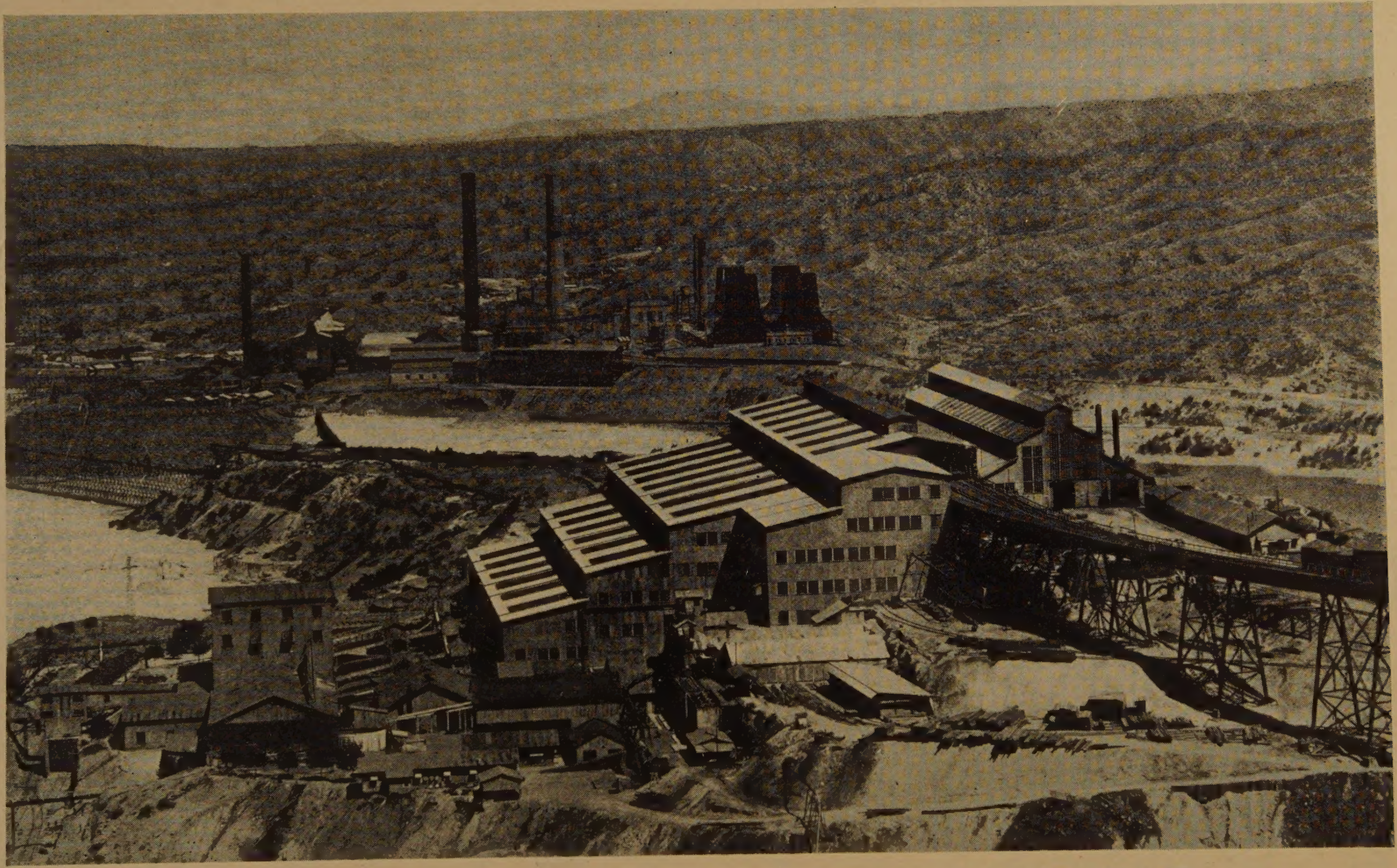
THE DESERT AREAS YIELD THE GREATER PART OF THE WORLD'S COPPER



Concentrator of the Inspiration Consolidated Copper Co., Inspiration, Ariz. (in foreground); and Smelter and Power Plant of the International Smelting Company (in background)

A complete copper plant for sulphide ore comprises the mine; the crushing plant; the concentrator, an intermediate process for low-grade ore; and the smelter. The product, blister copper, is shipped to the refineries, mainly along the Atlantic Seaboard. The refined copper goes to the manufacturers of castings, shapes, wire, brass, etc. (See page 214.)

GENERAL ELECTRIC REVIEW

CHARLES A. COFFIN FOUNDATION AWARDS

From time to time during the past year, we have told of the awards made by the Charles A. Coffin Foundation, beginning with the story of the award of the Charles A. Coffin Medal to the Southern California Edison Company, and ending with the announcement in this issue, of the distribution of Charles A. Coffin Certificates of Merit and cash to 48 employees of the General Electric Company. The committees administering the Foundation have had difficult tasks in all phases of its activity, but certainly none were as difficult as making this interesting selection of a small group of men and women from among over eighty thousand employees.

One of the first questions that arose was, what shall be the nature of the yard stick which will measure the accomplishments of men and women doing work as diversified as that of a clerk, a machinist, a salesman and an engineer. The decision was reached to compare the accomplishments of shop workers with other shop workers, foremen with foremen, engineers with engineers.

But still the problem of valuation of achievement remained unsettled. When the awards were made to the engineers on February 29th, Francis C. Pratt stated that after considerable study it had been decided to make the test as similar as possible to the tests long in use by military forces in granting medals of honor. In battle, bravery in face of fire is required of all soldiers, risking of life and limb is the general demand of the hour and the man who wins a medal must do even more than these things—he must successfully carry out the most intrepid feats of valor and skill exceeding all his fellows.

So in the case of the Foundation Awards, the universal test was not whether a man had done an assigned task excellently, but whether he had done more than that and had accomplished what his superiors had no reason to expect he would or could accomplish.

Under this general requirement, a consulting engineer such as Mr. W. L. R. Emmet in order to receive an award had to achieve the most extraordinary results, while a clerk in the Accounting Department had only to perform with high efficiency some task to which no glamor ordinarily attaches itself.

Still in his field and considering his opportunities, a clerk or machinist, or assembler, may have wrought greatly and left a deep mark upon methods in use in his particular office or shop.

The general verdict has been that the committee used its test with rare skill in this interesting industrial experiment.

The word experiment is used advisedly, for when in the past have honors such as those at the disposal of the Charles A. Coffin Foundation been awarded in a single day to clerks, machinists, stenographers, draftsmen, and foremen, as well as consulting engineers? The awards of the Foundation are creating an aristocracy of men and women who achieve, which by its very nature is permeated with the democratic spirit of American industry.

An account of these awards to the employees of the General Electric Company is published in this issue. W. W. T.

Copper and Electricity

By N. R. Stansel

Industrial Department, General Electric Company

Copper is a predominating factor in the electrical industry and therefore the engineer, the commercial man and the layman are all interested in it and its production. The author gives a long account of the copper industry, touching on its many different phases. This article is not technical in the general sense, but deals with a technical subject in a language understood by all.—Editor.

Ancient history records the use of copper in many ways and copper mining in some form was one of the earliest industrial activities of the human race. The peoples of Asia Minor and the Nile Valley were the first to pass from the Stone Age to the Bronze Age and as the use of copper antedated by several centuries the discovery of tin it seems reasonable to believe that a Copper Age was an important period in the growth of the first civilization. This viewpoint is supported by the many copper tools and ornaments—rather than instruments of warfare—left by the early inhabitants of these areas. Following the records of other races of mankind, copper as an industrial metal is likewise their emblem of progress towards the era of written records of race achievements. Thus early in the dawn of the human race Nature provided a metal suited to the elementary brain and handiwork of man so that he could start the development of the civilization which is ours today.

At the beginning of the eighteenth century the Cornish and Welsh mines of Great Britain produced about three fourths of the world's copper, the remainder coming principally from Russia and Japan and some small amounts from other countries, the total amount per annum not exceeding twenty million pounds. In 1800 A.D. there was no electrical industry. A few years later the birth of electricity as an art was through a copper wire the result of Faraday's epoch-making discovery of the reciprocal relation of electricity and magnetism. Today the production of copper is at the rate of about two billion pounds per annum and the electrical industry represents a capital expenditure of approximately five billion dollars, an industry made possible by the properties of copper which forms so large a part of electrical machinery.

At the present time approximately one half of the copper produced is used by the electrical industry, and the copper industry is in the front rank of the industries in its general use of electric power. About one half of the electrical quota of copper goes into the structure of generators, motors, transformers, etc., and the remainder of this quantity of copper is used for electric light and power circuits, telephone and telegraph lines and kindred electric service. Electricity plays some part in every stage of copper production, from the electric spark which fires the explosive charge to shatter the rock that contains the copper ore to the final process of refining the copper by electric current.

The growth in the use of copper, the consumption having doubled in each ten-year period since 1890, is reflected in the ratio of copper production and the production of pig iron. For many years this ratio was about one to eighty-three. The growing appreciation of copper as a valuable ally to iron and steel is shown by the decrease in this ratio during the past ten years. Now we produce one pound of copper for each fifty-five pounds of iron and it is significant to note that this represents an increasing domestic use of copper inasmuch as during this recent period of years the foreign demand for copper has been comparatively small.

The statistics of copper utilization place copper next to iron in its importance as an industrial metal, and in addition to its special adaptation in the manufacture of electrical equipment copper is widely used in the arts: the automobile industry is the second largest user of copper; this metal forms an important part in many types of machinery other than electrical, as a part of brass it is in common use but not recognized, our railways and ships find copper of great value, the copper coin has found a new use in the street railway industry and in a multitude of ways copper is an indispensable item in our affairs. In many lines of trade the estimate of value is based upon the amount of copper contained in the manufactured article.

To the layman copper among other metals comes from the ground. Beyond this elementary knowledge it is of interest to go further into the source of copper and to gather a general idea of how this well-known metal is produced. The United States with an

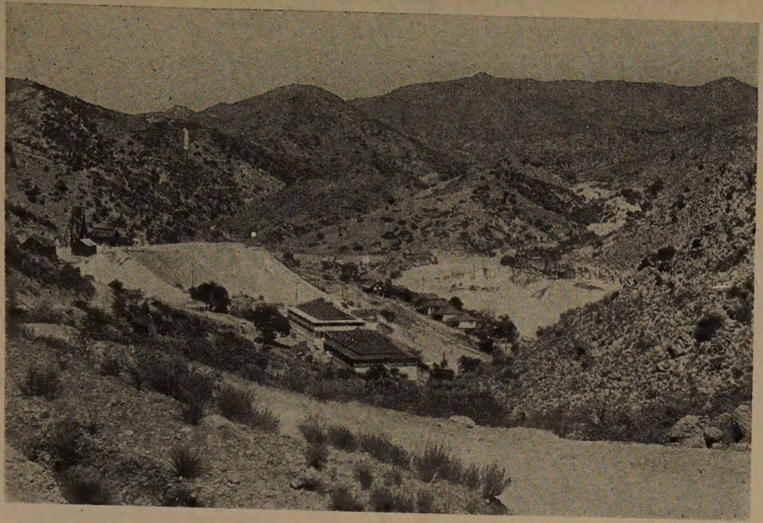


Fig. 1. The First Stage in the Development of a Large Copper Mine. The Inspiration Consolidated Copper Company, Inspiration, Arizona

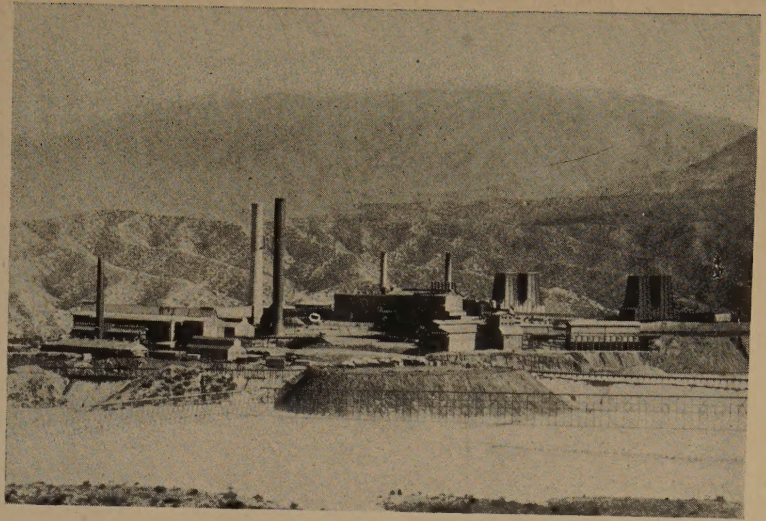


Fig. 2. A Modern Copper Smelter. The International Smelting Company, Miami, Arizona

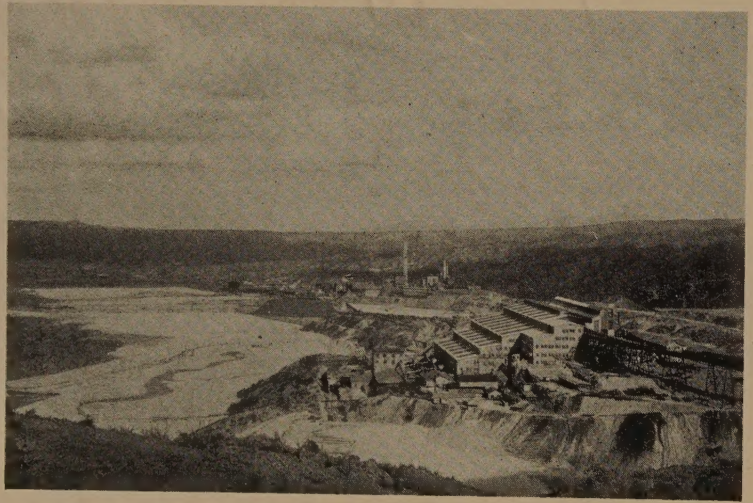


Fig. 3. A Tailings Pond. The finely ground rock is separated from the metallic particles of the ore and left behind, the "concentrate" going to the smelter in the background

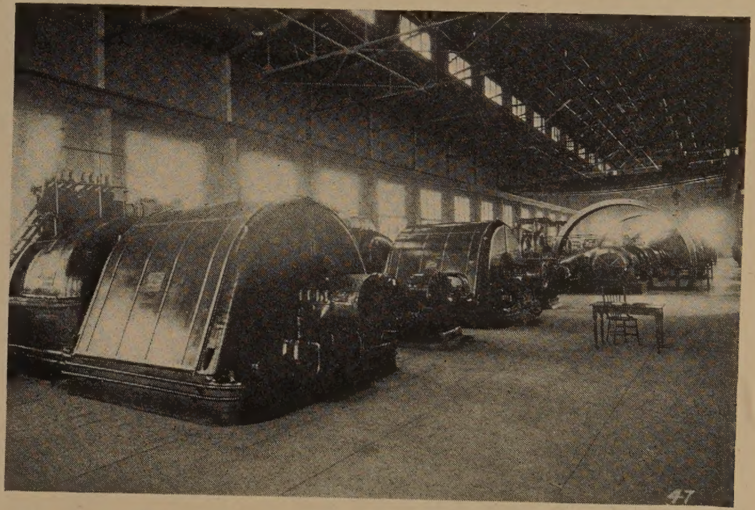


Fig. 4. Power Plant of the Miami Copper Company, Miami, Arizona. For low-grade ores the cost of power is a large item in the cost of producing copper

annual output of over one billion pounds is the center of the world's interest in copper. South America with a production of about one half billion pounds per annum is second in importance. Also copper is produced in other parts of the world. The oldest copper mine which is now in operation is the Rio Tinto in Spain where copper was mined in the eleventh century before Christ. Copper mining in the United States began in New Mexico about 1800 at the Santa Rita Mine, now operated by the Chino Copper Co. In the early days this mine was worked by the Spaniards, the ore being sent by pack trains to Mexico. About 1845 copper mining started in the Lake Superior district of Michigan, then followed the mines of Tennessee around 1850, the Butte district of Montana about 1868, and around 1873 the State of Arizona began the production of copper. During recent years Arizona has led other states in the output of copper, and next in order are the states of Utah, Montana and Michigan.

With the exception of a certain amount—usually small—of native or metallic copper found in practically all copper mines, and particularly in the Michigan districts, copper is obtained from various copper ores; defining an ore as a metaliferous mineral containing a useful metal or metals in such quantities as to make extraction of the metal or metals profitable.

The principal copper ores are divided into (*a*) sulphides, such as chalcopyrite containing 34.6 per cent copper, chalcocite containing 79.8 per cent copper, and others; (*b*) oxides for example, cuprite containing 88.8 per cent copper; (*c*) sulphates, one of which is brochantite containing 56.5 per cent copper; (*d*) carbonates, such as malachite containing 57.27 per cent copper, and (*e*) silicates, for example, chrysocolla containing 36 per cent copper. The ores may be found in bodies of more or less individual occurrence or scattered throughout a mass of valueless minerals. The terms "high grade ore" and "low grade ore" apply in general to the distinctions between ores which contain varying quantities of mineral of no value. This classification of ores is useful in following methods of treatment of ore to recover the metal. The high grade ore, rich in metal content, can be smelted direct as it comes from the mine. The treatment of low grade ores is a longer chapter of the industry's methods.

Taking into consideration the wide variations in the natural distribution and characteristics of ore bodies to which no simple rule applies it is convenient to consider next the zones of copper ore occurrence, an upper oxidized zone and a lower sulphide zone, giving three broad classifications of ores, viz., oxidized ores, sulphide ores and mixed oxidized and sulphide ores. In addition to copper the ores may contain—and frequently do contain—other metals, gold, silver, lead, etc. High grade ore may occur in either zone, likewise low grade ore occurs in both zones. The oxidized ores include the sulphates, carbonates, silicates and oxides from which the copper can be obtained by leaching with sulphuric acid if the ores are not sufficiently high grade to warrant direct smelting in the blast furnace. The low grade sulphide ores cannot be leached with acid and must be reduced in bulk, that is, concentrated, before smelting.

Up until recent years the bulk of the copper has come from high grade sulphide ores. The high grade ore bodies are limited in extent and now the low grade ore bodies containing say less than 2 per cent of copper are becoming more and more important. The "porphyry coppers" is a familiar term to many interested in copper stocks. The so-called porphyry copper ores refer to copper minerals disseminated in small grains throughout the associated rock. Some years ago these large bodies of low grade ore were not classed as ore. With the advance in metallurgy these deposits have become of great value and now an appreciable part of the total copper comes from these mines. However, in explanation it is noted that not all bodies of low grade copper ore are classed as porphyry ore.

Mining, the first process in the production of copper, is the extraction of the ore from the ground. The location of the ore bodies with respect to the surface determines whether the removal of the ore by surface or underground methods is more economical. The term "mine" is generally understood to refer to operations underground; however, there are both surface or open pit mines and underground mines. Ore bodies may be large or small, near together or widely scattered, some near the surface and others at great depths. Ore may occur in vein or lode formation or in a blanket formation of varying thickness. A large body of ore near the surface is mined by first removing the overburden and then the ore by power shovels. To reach ore at a depth beyond the range of surface operation a shaft is sunk, tunnels driven into the ore and the ore removed through these openings.

The central figure of the surface mine or open pit is the shovel which can be operated by steam or electricity. During recent years the electric shovel has been introduced and is rapidly growing in favor for this class of work. The same advantages which electric operation has over steam operation are present in shovel work and while the steam shovel is self-contained and better fitted to isolated work, the electric shovel which makes unnecessary the individual steam plant of high maintenance cost is of great advantage for large or small scale operations within range of the electric power supply.

The essential features which make successful the application of the electric motor to shovel operations are the rugged construction corresponding to the vigorous operations of the shovel and a control which provides degrees of effort following the cycle of duty of carrying the bucket through its digging, moving and dumping functions.

The hoist is the connecting link between the underground mine and the surface plant. The efficiency and flexibility of electric equipment together with its inherent safety in such operations makes the electrically driven hoist particularly well suited to any hoisting service. In addition to duplicating the service of any other type of hoist, the electric hoist adds a smoothness of movement and a control, partially or wholly as may be desired, independent of the human element in operation.

Several types of electric hoist apparatus are available, the distinguishing feature in each case being the control and the selection of control equipment is a most important consideration in hoist engineering. In the majority of cases the power supply is alternating current and while the power required by the hoist can be met by the direct application of the alternating-current motor to the hoist it is quite often the case that it is better to interpose direct-current machinery between the alternating-current motor and the hoist, for the improvement in the control thus afforded. This is the well known Ward-Leonard system of control which, in addition to providing a perfect and a safe control over the movement of the hoist, also lends itself to the effective utilization of a flywheel to partially or wholly equalize the varying power requirements of the hoist so that this load will not interfere with the voltage regulation of the system.

There is considerable variety to the water problem of the copper mining industry. Among the first undertakings in the development of milling and smelting operations is to provide an adequate water supply. The underground mine may be wet or dry. If water is encountered the flow may be great or small, it may increase as the depth is increased. If the mine is dry or if the mine is too far away from the surface plant a separate source of supply for mill and smelter must be provided. The mining engineer deals with both the permanent ground water and the surface water which seeps into the underground openings. As the depth of the mine is increased, new and often unexpected water channels may be encountered. The flow of water due to seepage is more certain and varies with the seasons. Underground water varies widely in temperature and in analysis and is frequently acidulated. The quantity of water from each level and the head—which may be divided into one or more steps—together with the above noted factors influence the selection of the type of pump.

The economy and flexibility of electrically driven pumps enables the industry to pro-

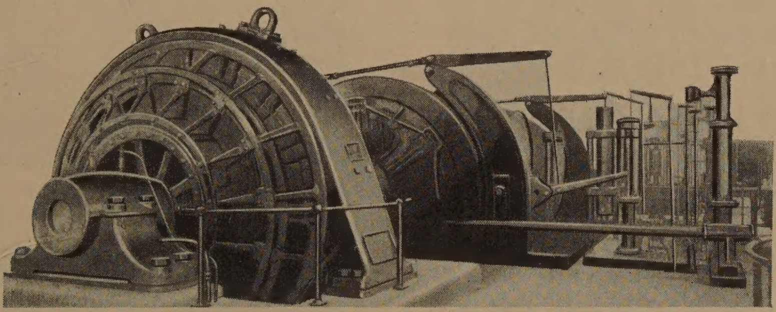


Fig. 5. First Motion Double Drum Electric Hoist.
Elm Orlu Mining Company, Butte, Montana

vide for its water in the way best suited to other parts of the work. Small units or large units, located as may be desired and controlled from any point, make electric pumping the ideal solution of this phase of the mining industry. Other than observing the requirement of providing insulation for damp locations and humid atmosphere and sometimes high temperature the selection of motors for underground pumps does not differ from the general engineering of pumping installations. The squirrel cage induction motor is a favored type but both the slip ring type induction motor and the synchronous motor are used for underground pumps. The type and size of pump is the guide in the selection of the type of motor.

The Tombstone district of Arizona—in the early days a prominent silver district—met the fate of a greater flow of water than could be handled. The several mines of the Warren-Bisbee district of Arizona are drained to a common point, thus centralizing the greater part of the pumping for a large area of underground workings. At the Old Dominion Mine, Globe, Arizona, the mine pumps must operate day and night and since 1914 have been pumping an average of four and one half million gallons of water per day. This mine has 13 motor-driven pumps, part plunger type and part centrifugal type, all operated by squirrel cage induction motors having moisture-resisting insulation and in sizes from 100 h.p. to 250 h.p., inclusive. It is of interest to note that a part of the water from this mine is utilized by the Miami Copper Co. in its mill some seven miles away, the mine of the latter company being comparatively dry. The permanent ground water of the twenty-second level of the Old Dominion Mine has a temperature of 110 deg. F. while the seepage water of the upper levels is cold enough for drinking and is pumped to the City of Globe for domestic use.

Water is the universal solvent, hence it is not uncommon for water from a copper mine and water that has been used around a copper plant to contain copper in solution. This water is passed slowly over orderly piles of scrap iron, often including many tin cans, and the iron replaces the copper in solution, the copper is precipitated in an impure form which goes to the smelter for treatment.

Underground work has no daylight advantage. All work is done by artificial light and this brings to our attention the important bearing that light has upon the well being and efficiency of the workmen. This has been demonstrated so conclusively in those industries where all work is above ground and where artificial light is necessary only to supplement daylight and for night operations that the importance of light is officially recognized by several states through the adoption of legal standards of illumination, such codes having as a basis the preservation of eyesight. The eye is perhaps the most valuable organ of the body and this organ requires light of correct quantity and quality for not only its proper functioning but in addition for its health. In continued darkness or unnatural light the eye gradually fails and for this reason alone the use of artificial light deserves much consideration. Aside from the importance of light to the health and contentment of the underground workmen, increased production is a direct result of improved lighting standards. In addition, the degree of safety underground is influenced to a marked extent by the amount and quality of light provided.

These three factors, health, production and safety is the argument that illumination offers to the mining industry and it is easily recognized that electricity is the medium for obtaining the desired result. A first consideration in raising the standard of illumination is the appreciation that the output of the electric lamp is only raw material and unsuited for use without modification in the way of diffusion and distribution. Bare lamps are an unnecessary evil and while at certain underground locations they may serve some purpose the general use of lamps without accessory equipment of shades and reflectors makes impossible the quality of light required by the eye. The often widely scattered working force underground may seem to make the provision of adequate illumination not worth while except at areas of concentration, but at least it is deemed worth while to recognize continuously the value of light and to establish higher standards of illumination.

Many of the problems of underground lighting are similar to the well developed methods of street lighting and these principles can be applied with such modifications as are needed to suit underground conditions. The silhouette effect is valuable, often serving the same purpose as more elaborate illumination. The light absorption and light diffusion properties of surface finishes can be studied and advantage of surface finish can often be utilized. A high standard of illumination does not mean a great volume of light. The eye works equally

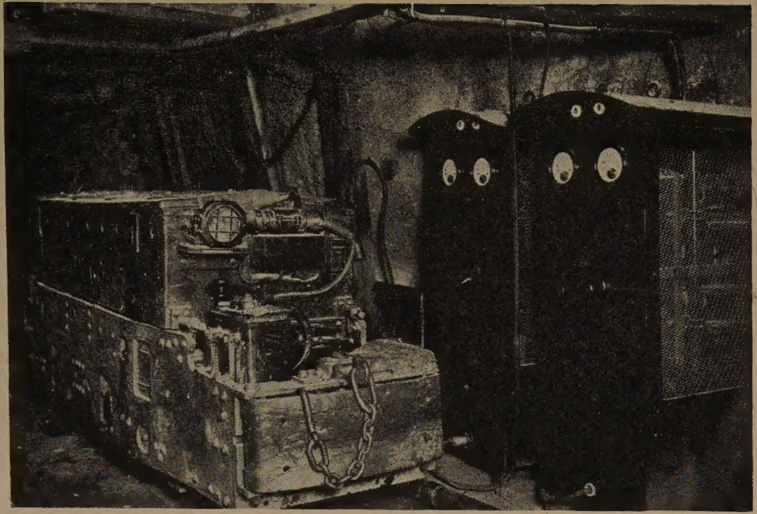


Fig. 6. Storage Battery Locomotive and Charging Stations. Anaconda Copper Mining Company, Butte, Montana

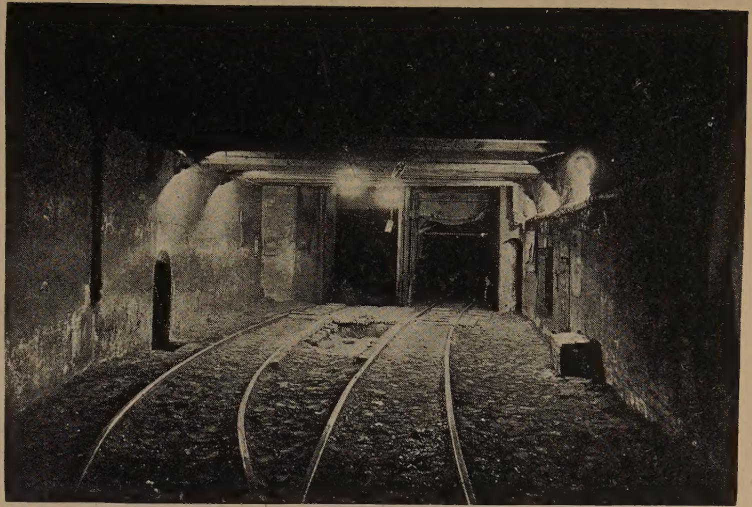


Fig. 7. Good Illumination Adds to the Comfort, Efficiency and Safety of Underground Work

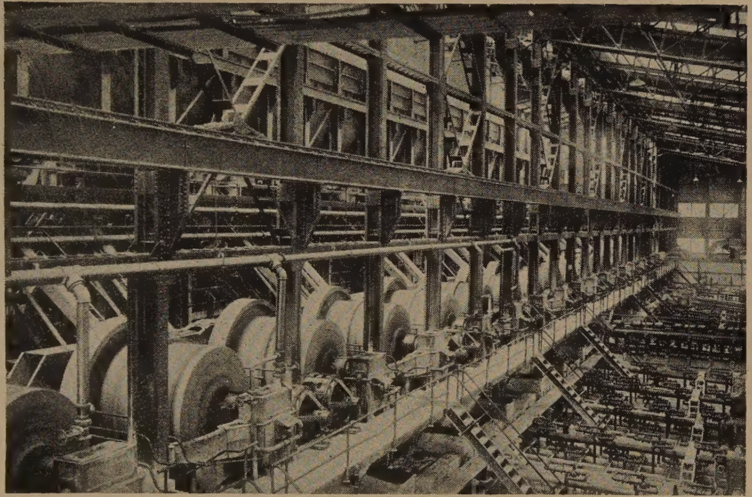


Fig. 8. Ball Mills and Flotation Cells of a Concentrator Treating Low-grade Sulphur Ores. Inspiration Consolidated Copper Company

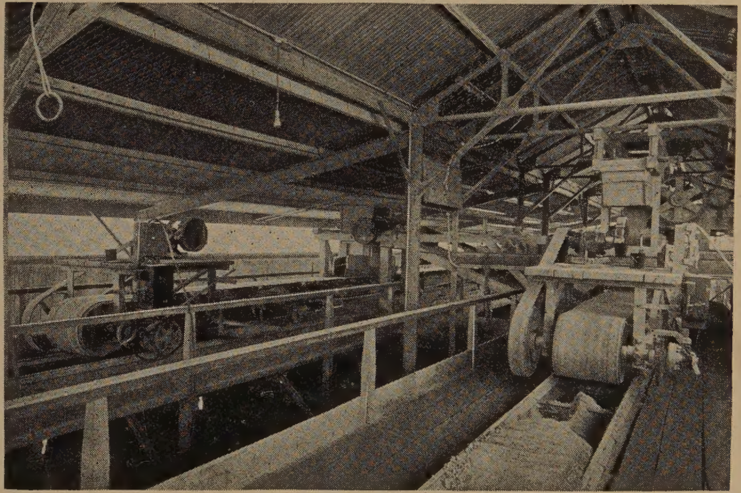


Fig. 9. Motor-driven Belt Conveyors are an Important Feature of Ore Treatment Plants

well over a wide range of light intensity provided the light is of good quality. This means care in providing a diffused and well distributed light and this is termed good illumination. A haulage tunnel in which headlights are not needed on the locomotives suggests the thought of an underground illumination that is designed to facilitate and make safe underground work and illumination that is considerably wider in its scope than is generally deemed necessary.

The Mazda lamp is the generally accepted standard and there is a sufficient range of sizes to meet all underground conditions. Where for some reason it is necessary to use bare lamps the all-frosted lamp is desirable except of course when colored lamps are used as signals or markers. In fact, as there is but little difference in the life and efficiency of the frosted lamp and the clear lamp, the general use of the frosted lamp using the same accessory equipment as for clear lamps would materially improve the illumination. In the use of shades and reflectors it is desirable to avoid a feeling of darkness overhead. That is, the total amount of the light of the lamp should not be directed downward but a small amount should be permitted to reach the roof, thereby creating a more natural effect. Glass top reflectors—with or without the glass—are useful for this purpose. Glass is the best material to use for the diffusion and distribution of light but it is generally considered too fragile for underground service. However, prism glass is comparatively strong and, in many places underground where the construction is of a permanent nature, prism glass in the form of shades and reflectors is an excellent form of lamp accessory equipment.

Good voltage regulation of lighting circuits is necessary to provide good illumination. Usually it is practicable to provide separate lighting circuits and when this is done the normal voltage regulation of the system is generally sufficient. When it is necessary to supply the underground lighting from a common feeder for both power and light and the voltage regulation at the point of distribution is poor, a voltage regulator for the lighting service will be worth while.

The copper mineral is found in rock formation and blasting is necessary to break up the ore for removal. The first work is drilling the holes in the rock for the reception of the explosive charge. Various types of electric drills have been developed but none has proved to be a serious competitor of the compressed air drill in the copper mines. In this case electricity is an indirect application of motors to drive the air compressors.

Powder in some form, e.g., dynamite, has been the universal explosive charge to break up the rock, the firing of the charges being either by fuses or by electric ignition. Recently a new form of explosive consisting of some form of carbon and some other inert matter saturated with liquid oxygen has been introduced. The unique feature of this explosive is the evaporation of the oxygen within a short time unless the charge is fired. In this way a "missed" hole is not dangerous.

Transportation underground is handicapped to some extent by the small areas of tunnels. Openings through rock is expensive construction and the areas of all underground openings are kept to a minimum. As the tunnels are passageways there is usually ample headroom for haulage but the width is limited necessitating narrow gauge tracks. The grades are small, usually in favor of the load. With the exception of main haulage tunnels, where the movement of the ore is concentrated, the underground traffic is both light and irregular. The usefulness of electric haulage is here not so much a matter of its economy of power—which is but a small part of the total cost of mining—as the effectiveness of the application and this is the way the electric locomotive contributes to the overall economy of ore production.

The direct-current locomotive is almost exclusive in the field of underground haulage. In some few cases alternating-current locomotives have been installed; however, the added complication of the two trolley wires, the reactance of the rail circuit and the space limitations more than offset any advantage which can be obtained by alternating-current distribution and to this is added the superiority of the direct-current motor for haulage service.

With the growth in the extent of underground operations the need for artificial ventilation has increased. There is always pressure on the air in mines. This is true whether the column of air is vertical or at a slope, and is caused by the difference in temperature of the incoming and outgoing air. This pressure forces air through the openings of the mine and the volume of air passing through the mine varies directly with the pressure and inversely with the resistance of the air passages. This natural circulation, however, has little effect upon pockets and openings with closed ends, adits, etc., where men may be at work.

Although natural circulation of air may be sufficient for small mines it is of limited value for ventilation to provide an adequate fresh air supply for men underground. The motor-driven fan provides a definite circulation of air independent of natural conditions of temperature, surface air velocities, etc. Both the portable motor-driven fan in small sizes and the stationary motor-driven fan in all sizes are available. For the smaller fans, the constant speed squirrel cage induction motor is generally used. For the larger fans either the induction motor or the synchronous motor is suitable. If it is desired to vary the volume of air from time to time either the slip ring type induction motor or the adjustable speed brush-shifting commutator alternating-current motor is available. The latter type of motor is more efficient at reduced speeds than the slip-ring type induction motor with its necessary external resistance.

The highly developed methods of extracting ore from the mine are followed by equally complete methods of treatment on the surface through the several processes from the ore to the copper ingots. The surface operations can be termed manufacturing by elimination as distinguished from manufacturing by combining raw materials into a finished product. The cost of production of the metal is largely determined by the careful balance of the extent to which each of the several stages of treatment is carried.

The ore comes from the mine broken up only small enough for convenient handling in the skips of the hoist or cars of the haulage system; ore brought to the surface in skips is necessarily smaller in size of lumps than the ore moved in cars from an open pit mine. In order to release the mineral particles from the rock it is necessary to subdivide the ore, the fineness of this process depending upon the method of extraction to follow. For leaching the final reduction is to about three quarter-inch cubes, for the flotation process very fine grinding is required. The first reduction in the size of the ore lumps is by crushing, a dry process, divided into stages, primary and secondary, and in some cases a fine crushing stage is added. In one plant the ore is delivered by the skips to a receiving bin and then passes to primary crushers which reduce the lumps to 3½-in. cubes and is followed by the secondary crushers which deliver a product with lumps of a maximum dimension of one and one half inches. At another plant receiving ore from an open pit mine the first reduction is to 8 in., the secondary crushers reduce to 3 in. and the fine crushers finish to a reduction of ¾ in.

Gyratory crushers, jaw crushers, rolls and disk crushers are used, the selection and arrangement as to primary and secondary stages depending upon the character of the ore, initial size of lumps, and the extent of the reduction by crushing. Both belted and direct connected motors are used for crushers. The belt drive offers a certain flexibility but has the disadvantage of extra space and belts slipping under overload conditions. The service of the primary stage of crushing is severe, the load varying widely, the variations being approximately in proportion to the size of the lumps of ore fed to the crusher. As the lumps of ore become reduced in size the load of the succeeding crushers becomes more uniform. For the primary crushers, motors of ample size for the maximum load are a good investment. The motors for the secondary crushers can be rated more closely to the average power required.

The first large scale development in the treatment of low grade ore was the production of copper from the sulphide ores and this continues to be an important branch of metallurgy. Without attempting scientific accuracy we may follow this process by commenting upon the operations through which the low grade sulphide ore passes through the concentrator and smelter.

From the crushing plant the ore is delivered to the concentrator where reduction in bulk takes place. The modern concentrator is built on the unit plan, a convenient unit being one thousand tons of ore per day of 24 hours. Through the concentrator the ore follows a route designated by the flow sheet carefully worked out for the particular grade of ore being treated. Water and gravity is the main transportation system of the concentrating process. In the concentrator no change in the chemical character of the ore is made, the entire process being the elimination of waste material, i.e., rock. To release the metallic sulphide particles from the rock very fine grinding of the ore follows. This is a wet grinding process, about 1½ tons of water per ton of ore being used. The ball mill for fine grinding consists of a steel shell, an average size being 8 ft. in diameter by 6 ft. in length, with a cast-steel lining. The mill is charged with steel balls from 3 to 5 in. in diameter, in quantity so that the balls and ore occupy about 40 per cent of the volume of the mill. The ore and water are fed into one end of the mill, the discharge being at the opposite end. The mill is rotated slowly, about 17 r.p.m., and the continuous action of the steel balls grinds the ore which is discharged as it reaches the desired fineness, the product of the mill, termed pulp, flowing freely. The rod mill is similar to the ball mill, rods instead of balls being used for the grinding action.

The power input to the motors driving the ball mills and rod mills is determined by the weight of the mill and its load and the speed of rotation and does not vary with the output. The kilowatt-hours per ton of ore is determined by the character of the ore. The starting torque of these mills is high, about twice full load torque. The running load is constant except for a continuous and irregular variation, about 5 to 10 per cent, the extent of this variation depending upon the contour of the lining. Either the slip ring induction motor with double reduction gearing or the high starting torque synchronous motor and single reduction gear is suitable for driving these mills. In some cases a belt drive and a single reduction gear is preferred to a direct connected motor.

Concentration of ore by flotation is an interesting phenomenon and is now the general method of reducing the bulk of low grade copper sulphide ores. During the fine grinding stage a small amount of "oil" such as coal tar—about one pound of "oil" per ton of ore—is added to the ore. The pulp from the fine grinding mills flows to the flotation machines. One common type of this part of the plant is a combination of cells having porous bottoms and in which the pulp is agitated by low pressure air. In another form of flotation machine the agitation of the pulp is mechanical. A peculiar property of the sulphide mineral particle is that it is coated with a film of the coal tar "oil." Agitation of the pulp aids the oil in its function of coating the metallic particles, and then assisted by the air bubbles the phenomenon of surface tension and possibly other phenomena the sulphide particles rise to the surface, i.e., float and overflow and pass onto the filters for removal of the water from the mass. In this way the light particles of the ore sink and the heavy particles rise to the surface. The waste rock still carrying a certain amount of mineral value due to incomplete separation in the flotation ells flows from the bottom of the flotation machine for additional treatment. This second stage of separation is usually on concentrating tables where by a shaking motion the difference in the specific gravity of the metallic particles and of the waste rock causes the separation of these two parts of the pulp.

The product of the flotation machines and of the tables is termed concentrate, that from the flotation process containing around 40 per cent copper and the product of the tables about 20 per cent copper. The sulphide ore usually carries some oxidized ore but little of this appears in the concentrate. The concentrate after being dried to a point where it contains from 12 to 17 per cent moisture is ready for the smelter. The entire extraction of the sulphide mineral is about 90 per cent and for, say, a 1.2 per cent ore, some 30 to 35 tons of ore are reduced to one ton of concentrate.

Crushing, grinding and conveying the ore and pumping of the large volume of water require a considerable amount of power. It is convenient to remember that for this work approximately one kilowatt per ton of ore per day is needed, the exact amount varying with the hardness of the ore, extent of grinding, amount of water pumped, etc. The ore flows in a continuous stream through the mill—or concentrator—day and night and the motors have no rest periods. Here again the flexibility and high efficiency of the electric motor has made it possible for the engineer to design the plant with entire freedom in the selection and arrangement of machinery to obtain a minimum cost of ore treatment.

The first change in the chemical composition of the sulphide ore is made when the concentrate reaches the smelter. The ore contains a considerable quantity of sulphur and the smelting process begins with burning off this sulphur and this burning of sulphur continues throughout the process. The concentrate first goes to the roaster. Here a part of the sulphur burns but the heat is not sufficient to cause fusion. The product of the roaster is calcine. The calcine while still hot is fed to the reverberatory furnace which requires fuel, either oil or powdered coal, and here fusion takes place. The molten mass separates by gravity, the melted rock and other impurities constitute the slag which rises to the surface and is drawn off, and disposed of as waste. The molten metal is likewise drawn off, this product of the furnace is designated as matte and contains from 20 per cent to 45 per cent copper. The lower the grade of the matte the less copper left in the slag.

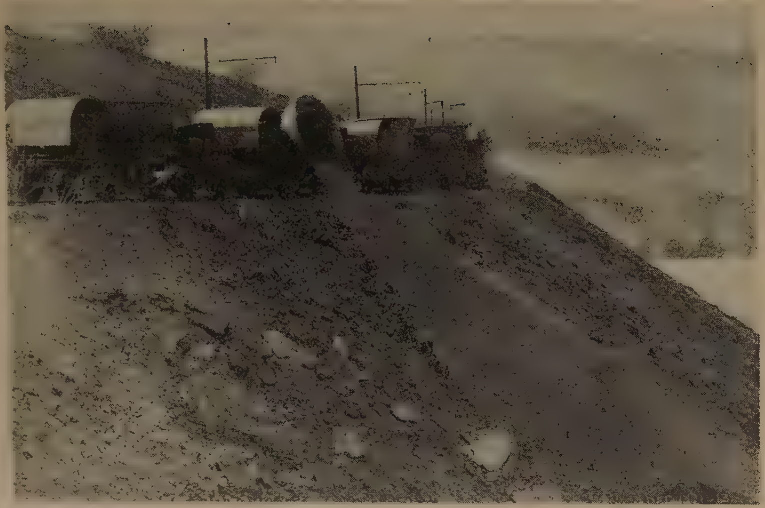


Fig. 10. A Slag Dump of a Copper Smelter. The slag is now used as railroad ballast

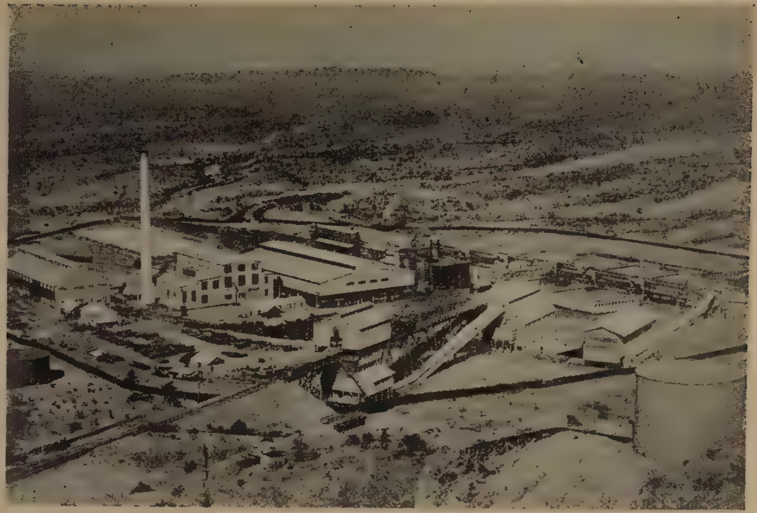


Fig. 11. A Plant Treating Oxidized Ores by Leaching and Electrolytic Extraction. New Cornelia Copper Company, Ajo, Arizona

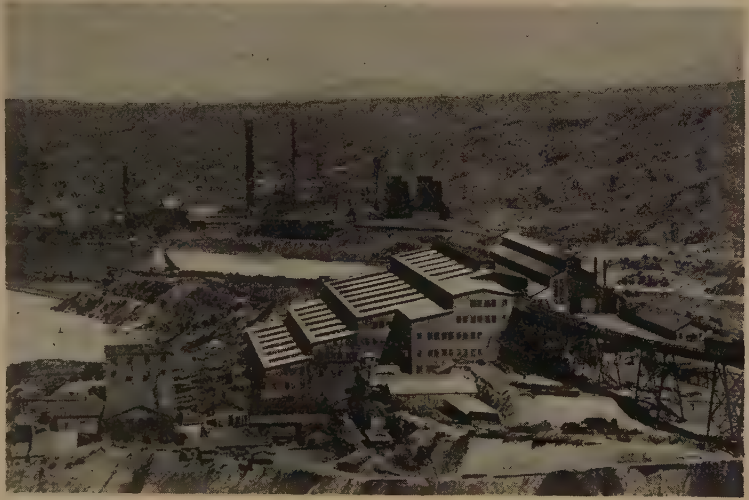


Fig. 12. Day View of a Large Copper Plant in Arizona

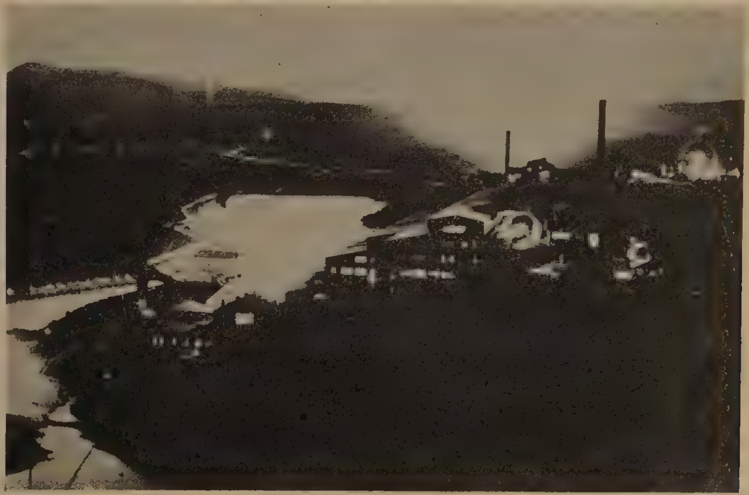


Fig. 13. Night View of the Plant shown in Fig. 12. Illustrating the continuous operation of the copper industry

The copper matte in a molten state is transferred direct from the reverberatory furnace to the converter. Free silica is added to the charge in the converter and air under 10 to 15 lb. pressure is blown through the molten mass. The sulphur in the matte is the fuel, this burns forming sulphur dioxide, the iron is oxidized and forms a slag with the silica. This slag being much lighter than copper is skimmed off and as it contains a certain amount of copper is returned to the reverberatory furnace. After the oxidization of the charge is complete and after the slag has been removed the copper is ready for pouring into moulds. The product of the converter is termed blister copper, this term being due to the appearance of the surface of the ingot. This is a high grade crude copper from which nearly all of the impurities have been removed, the ingots being approximately 99 per cent copper. Amid the heat and fumes of the smelter electricity furnishes the driving power for the roaster, the cranes which handle the huge ladles of hot metal, the converters, and slag cars; pumps the water, compresses the air, provides light and is the general servant which maintains continuous operation, an essential feature in heat processes. A considerable amount of heat is a by-product of the reverberatory furnaces, and steam boilers are placed adjacent to the furnaces to provide steam for the generation of electric power.

Where rich ore is available blast furnaces form a part of the smelter equipment. The high grade ore is fed into the blast furnace, coke is used for fuel, silica is added for fluxing and fusion takes place, the general character of this operation being similar to the reverberatory furnace.

Large volumes of gas are produced by the smelting process and this gas carries metal values in suspension. The recovery of this metal by means of electric precipitation is yielding considerable revenue to the industry. At present arsenic is being produced in large quantities by this method. Electric precipitation of the suspended metallic particles is accomplished by passing the gas through a uni-directional electrostatic field in which a corona discharge is maintained. A chamber in which vertical electrodes are supported and of a size corresponding to the volume of gas to be treated directs the flow of gas through the spaces between the electrodes. The electrodes are maintained at a potential to produce the corona discharge and just below the spark-over point. The result of the electric phenomenon involved is the deposition of the metallic particles from the gas on the electrodes from which it is removed by shaking.

The electrical equipment of the precipitation unit consists of a step-up transformer, the high voltage ranging from 25,000 to 100,000 volts, and a rectifier to give the uni-directional current, measured in milli-amperes. The mechanical rectifier driven at synchronous speed introduces considerable variations in the voltage wave, lacking that uniformity in the electric circuit so desirable where a high voltage is used. The vacuum tube rectifier provides a perfectly uniform voltage with corresponding improvement in the operation of the process.

The flotation process so successfully used for the sulphide ores is not adapted to the ores of the oxidized zone. The copper minerals of the oxidized ores are soluble in sulphuric acid and the utilization of low grade oxidized ores by leaching with sulphuric acid has made much progress during the past ten years. The copper is recovered from the ore as copper sulphate and the copper is extracted from the solution by the electrolytic process.

The preparatory treatment of the ore for leaching consists only in crushing the ore to ¼-in. cubes. The crushed ore is transferred to large lead-lined concrete tanks and dilute sulphuric acid is made to percolate through the mass, the leaching of a tank of ore requiring from seven to eight days. The resultant copper sulphate solution is pumped to the electrolytic cells in which are placed copper starting sheets as the foundation for the copper cathodes which are built up by copper deposited by the current from the solution. With lead anodes the voltage between anode and cathode is approximately two volts. Varying degrees of current density can be used, from 8 to 10 amperes per square foot of cathode area being average values. The average weight of copper per kilowatt-hour expended in the cells is 0.80 lb.

This process of treatment while very simple in outline is complicated by many factors and the successful applications represent a high degree of effort on the part of metallurgical engineers. Refined copper ready for use is produced and interesting experimental work in the production of copper articles of everyday use by direct deposition from the copper sulphate solution indicates wide possibilities for this method of extraction.

Only one other class of ore remains to be considered, the mixed sulphide and oxidized ores, which are abundant and represent the next metallurgical advance in the copper industry. Nature does not provide a uniform mixture and the varying degrees in which the mixtures of the minerals occur makes each ore body of this class an individual problem.

Extensive experimental work has demonstrated that the mixed ores can be treated successfully and as the separate bodies of sulphide and of oxidized ores of organized mining properties become exhausted the extraction of copper from the mixed ores will follow as a regular procedure of the industry.

To maintain a continuous flow of ore from the mine and on through the surface plant a continuous flow of power is required. A failure of power not only means a loss of production but at certain points such as pumping stations, crushers, conveyors, air supply, etc., serious losses may occur if the functions of the machines are stopped even for a brief period. This continuity of power supply depends in a large measure upon the integrity of the copper wires and cables of the power distribution system.

An adequate amount of copper in the circuits to provide ample current capacity and for voltage regulation, the insulation of the circuits, the protection from mechanical injury, the protection against injury to employees and sufficient duplication of circuits are the essential considerations in the layout of the conductors of the electric system.

For the main feeders underground a 3-conductor cable insulated with varnished cambric with a lead sheath and galvanized steel wire armor has proven to be superior to all other forms of circuit construction. This cable is carried down the shaft or drill hole as may be convenient, along tunnel walls or roof to centers of distribution. Only mechanical supports are necessary. The cable is sufficiently flexible to accommodate itself to the irregular surfaces underground and once installed requires no further attention. The lead sheath protects the insulation from moisture, a wrapping of jute and the wire armor protects the lead from corrosion and mechanical injury. This type of cable makes it feasible to safely carry 2200 volts—or a higher voltage if necessary—to underground centers of operations and at a moderate expense.

The underground secondary distribution becomes of less and less permanent construction as the circuits advance towards the working faces. For both permanent and temporary low voltage construction open runs of rubber-covered wire are suitable and a high grade rubber should be used for insulation.

All important feeder circuits underground should be protected against an accident at one point causing a general failure of power. This requires sectionalizing circuits and such interconnections as may be practicable. A comparatively recent development, the oil fuse cutout, is an effective aid in maintaining continuous service and protecting circuits from damage due to accidents. This type of cutout is well suited to underground work as it has no moving parts, is not affected by corrosion and stands up under rough usage.

In all phases of the production of copper a continuous analysis of each process is necessary to insure a minimum total cost. The measurement of power is a valuable guide in this work. Furthermore, a continuous indication of power flow through the distribution system is essential to a day by day knowledge of the efficiency of each class of work. In certain cases continuity of operation and variations in operation make desirable a written record of the flow of power. This history of each day's work makes close supervision possible. The electric meters of the electric system add each unit of power to the sum of previous units used and the total power for any division or subdivision of the plant for any period is available for analysis and comparison. The indicating instruments of the electric system make visible the distribution of power and thus indicate the rate of movement of all elements of production and show whether or not the degree of action for maximum production is being obtained. Curve drawing instruments are the recorders of degree of action, of continuity and of variations in operations. The selection of meters is closely allied to the accounting system and the installations of meters should fit into the general plan of the records of the organization. Both indicating and curve drawing instruments are a part of the operating organization.

The electrical manufacturer has gone a step farther in the field of electrical measurements in providing meters and indicating and curve drawing instruments to measure and indicate the flow of water, gas, air and steam, so that a complete and accurate control of every operation that uses power in any form is available to the industry.

Like a watch, meters and instruments are of little value unless kept in good condition. Periodic calibration of this class of equipment is necessary to insure value to its use. A meter or instrument without provision for a periodic check upon its function is of doubtful value. Standard instruments for comparison of all types of meters and instruments can be obtained and this important calibration work is both simple and effective.

However complete may be the methods and equipments of the mining plant the provisions for the health and contentment of the men must extend beyond the working hours of the day. In many cases large industries are not faced with any problems of living conditions, the surrounding community itself taking care of the domestic and social elements of the human assembly. Even so, many organizations have found that provisions for a wholesome and adequate noon meal is a valuable factor in the continuous solution of the labor problem. The copper industry is largely in sparsely settled areas and domestic and social structures must be maintained along with the more material plant equipment. Napoleon stated in concise terms the efficiency of man. Good materials and a good cook are essentials. It is not difficult to provide good materials and to the extent that the industry must provide for the cooking of food electric heat is pre-eminent in its aid in the production of good food. Proper cooking depends upon control of temperature, a certain temperature for a certain time for each article of food. With fuel this control is largely a matter of the skill of the cook. With the electric range and oven—built of any desired capacity—a mediocre cook is carried along in the production of good food. Also the elimination of the matter of fuel supply, the reduction in waste, and the promotion of cleanliness are concomitant advantages of electric cooking, all of which relieves the executive of a part of his burden. The extension of electric cooking to the homes of the workmen carries the same idea further and raises the standard of living at the very center of the sociological problem of the industry.

An important element in the effective use of electricity in any industry is standardization of equipment and methods of its use. This can usually be carried to its economic limit without interfering with the processes of the industry except in some cases when the developments of the industry are too rapid to permit of fixed general ideas. The copper industry has made and is making much progress towards the economical utilization of ores and this progress is based upon stabilized principles which permit wide scope in improvements of details from day to day as more and more knowledge of the art is obtained. Such progress permits much freedom in standardization and particularly so in the use of electricity which bends to suit conditions but does not break whatever may be the demands upon this tool of progress.

The copper industry has profited by the growth of the electrical industry because of the indispensable properties of copper in electrical machinery. At the same time the production of copper on the present large scale has been made possible by the utilization of electricity. This utilization has been mainly in the use of the electric motor and it remains to be seen to what extent the copper industry can further profit by a wider use of electricity. Prophecy has a large part in all human undertakings and the foundation of prophecy is a survey of possibilities of progress. The primary tool of the copper industry is fuel utilized in one form or another. Notwithstanding our enormous fuel resources the economy of the world points unerringly towards a better utilization of our stores of fuel and much progress towards making available our water power resources is being made. That economy which turns our attention towards water power is not scarcity of fuel but rather the cost of fuel is probably nature's way of self preservation. The generation of electric current by water power and its transmission to convenient points of utilization being well developed the next large stage in the use of electric power by the copper industry is the conversion of electric energy to heat energy. While electric smelting has a long way to go to reach the practical stage it is entirely reasonable to believe that the speed of our present day progress in science will not fail when it is deemed essential to arrive at a solution of the problem of electric smelting.

Railways of the Japanese Empire

By S. T. Dodd

Railway Department, General Electric Company

The author, who has only recently returned from a year's study of the Japanese railway system, writes a most interesting story of his personal observations. After some historical notes he describes the physical characteristics of the Imperial Japanese Railways. He cites some of the difficulties encountered in building railroads in the Island of Japan and describes the type of road bed, bridges, etc. In dealing with the rolling stock he makes some interesting comparisons between Japanese and American practice. He also compares the traffic density of our own and Japanese railways. A most comprehensive scheme of electrification has been decided on with 1500 volts direct current as a standard. This scheme calls for a total of 336 electric locomotives by the year 1928.—Editor.

The object of the present article is to give some personal observations on the Japanese Railway system as accumulated during a year's residence in Japan and by association and conversations with a number of railway engineers. These observations were previous to the disastrous earthquake which visited Tokyo and Yokohama on September 1, 1923. While the effect of the earthquake will be to retard or rearrange plans for railway development in and around these cities, it does not affect the history of the railway system nor the scenery along its lines and on account of its purely local character it will not ultimately affect the plans for future development. However, statements in this article are to be understood as subject to changes due to the earthquake.

The main facts in regard to the development of the system and the traffic over the lines are available from published statistics and the writer does not assume to contribute anything original on that subject. It may, however, be of interest to give a brief resumé of the facts.

The opening of Japan to trade with the western world began with the visit of Admiral Perry, in 1854, and the treaty which was finally signed between Townsend Harris, representing the United States, and Baron Ii of Hikone, representing the government of Japan. Fifteen years later, in 1870, the government began the construction of its first railway line under the supervision of British engineers by building an 18-mile line between Tokyo and Yokohama. This was open for traffic in 1872 and was followed by the construction of a line from Kobe to Osaka which was opened for traffic in 1874, and extended as far as Kyoto in 1877. While the first roads were owned and operated by the government, private capital soon turned towards this business as a profitable form of investment; and in 1883 the first line under private ownership was constructed, being a length of 38 miles from Ueno station in Tokyo to Kumagaya. This was the first part of the through line now running from Tokyo to Aomori at the northern extremity of the main island where connection is made with the northern island of Hokkaido. The profitable operation of that line stimulated private construction to such an extent that by 1894 there were 1305 miles of private railways in operation compared with 580 miles of government owned railways. Ten years later, about the time of the Russo-Japanese War, there were 3231 miles of private railways and 1461 miles of government railways.

The question of nationalization of the railroads of the Empire came to a head in 1906, after about ten years of discussion, and at that time seventeen of the principal of these private railways were taken over by the Government and incorporated in the Government Railway system. In taking over these lines the Government assumed all the obligations of the railroads, making payments for them in the form of bonds bearing a fixed rate of interest.

At the present time there are 7800 miles included in the Imperial Government Railroad system. As can be seen from the map, they follow in general the level coast line around the contours of the island but several branches cut across the mountainous country in the interior from one coast to the other.

The best known lines of the Imperial Government Railway System are: the Tokaido line running west from Tokyo to Kobe; the Sanyo line running from Kobe to Shimoneseki at the western extremity of the island of Hondo, and the Tohoku line running north from Tokyo to Aomori. Of these the Tokaido line is of particular interest to electrical engineers as this is the line which is proposed for complete electrification within the next few years. The details of the program of this electrification may

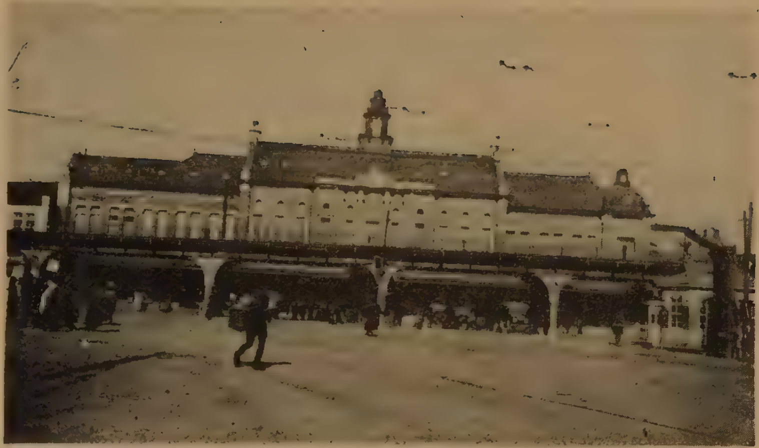


Fig. 1. Yokohama Station: A brick building with stone trim housing ticket and waiting rooms and offices; with platform on one side for steam through trains and on other side for multiple-unit trains

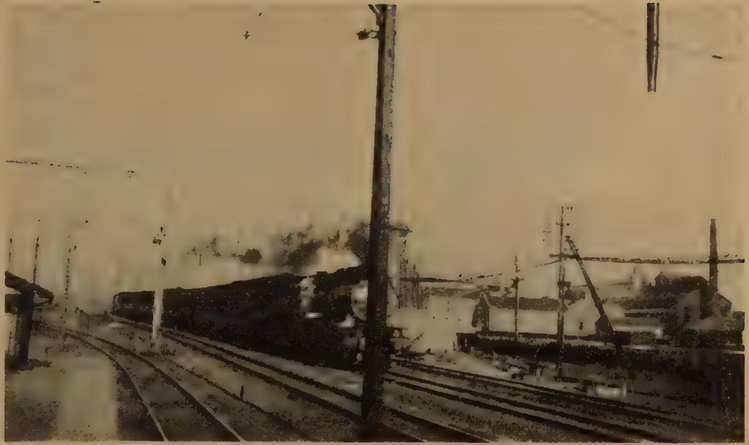


Fig. 2. Railroads in Suburbs of Tokyo. Multiple-unit trains to the left, steam tracks to the right; overhead construction is proceeding over the steam tracks

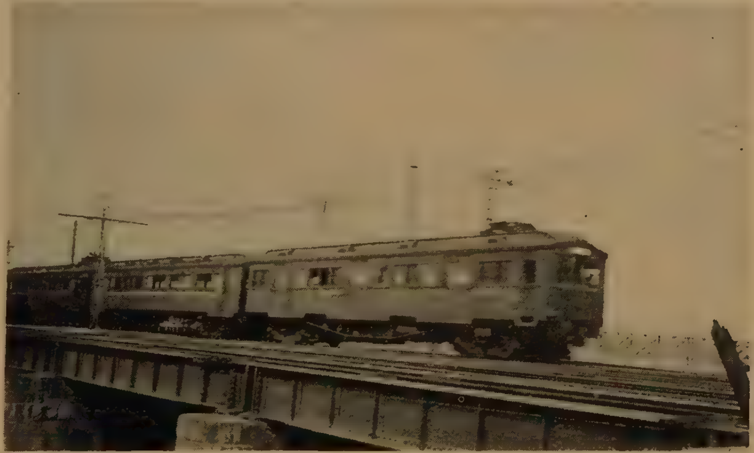


Fig. 3. Multiple-unit Train Between Tokyo and Yokohama. Five-car trains run on 12 minutes headway from 5 a.m. to 11 p.m.

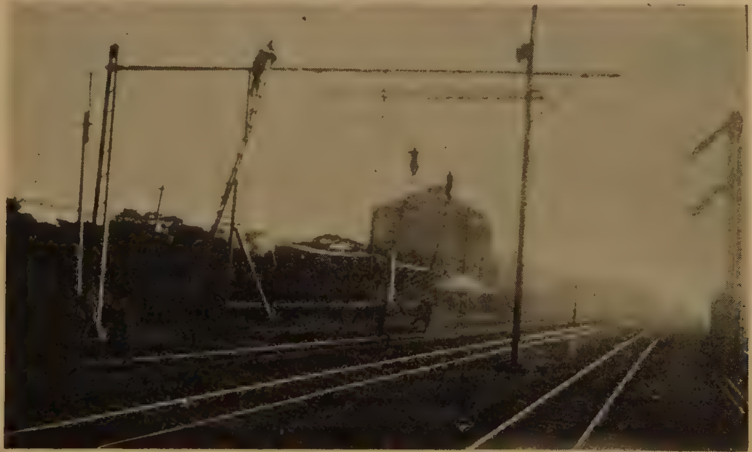


Fig. 4. Putting up Trolley Wire. Linemen are erecting poles and stringing trolley wires for the first 50 miles out of Tokyo preparatory to electric operation in this section

have been interfered with to some extent by the earthquake of September 1st, but according to the latest reports the Government intends to proceed with the original plan of electrification as rapidly as possible. It may be of interest to describe in some detail the physical features of this line.

Starting from Tokyo the first section as far as Yokohama is the 18-mile section which was first built in 1870. This is now a four-track line, over two tracks of which multiple-unit cars handle the suburban traffic between Tokyo and Yokohama. The other two tracks are occupied by the steam hauled traffic of the Tokaido Line. Beyond Yokohama the line runs through a level country largely given over to rice culture and generally following the seashore as far as Kodzu 48.2 miles from Tokyo. This is the section which has been proposed for the first electrification, and during the spring and summer of 1922, gangs of linemen were to be found along this section erecting poles and stringing electric wires for the trolley. The branch at Ofuna Junction (28.8 miles) turns south to Yokosuka, 10 miles farther, where is situated the Japanese Navy Yard. It is proposed to extend electric multiple-unit operation to Yokosuka and as a consequence the traveller finds gangs of track men building two additional tracks as far as Ofuna with the object of making a 4-track road for this distance, two tracks of which will be assigned to multiple-unit traffic from Tokyo to Ofuna and down to Yokosuka.

At Kodzu is met a spur of the Hakone Mountains which forms the Idzu peninsula. The mountains are impassable at this point and the present road turns north for the purpose of crossing the mountains at a lower grade through the Gotemba Pass. This next 35 miles presents some of the most difficult construction problems on the line. The track follows the course of a swift mountain stream and frequent tunnels, bridges, cuts and fills make the ride attractive from a scenic standpoint but show that the engineering and construction forces had a difficult job in locating and laying the line. Part of the line is on a grade of 2½ per cent and all heavy trains take a pusher from Yamakita to Gotemba over this grade. The line is running through the foothills of Mount Fuji and to the right are seen frequent glimpses of the slopes of its snow-covered peak. After passing Gotemba, the grade is down to Numadzu (85.6 miles) the end of the first engine division.

There is now under construction the Atami cut-off which when completed will eliminate the heavy grades of this section. For this cut-off the line turns south from Kodzu and follows the seashore through Odawara to Atami village. The construction is difficult as the mountains run steeply into the sea and frequent tunnels are necessary but the grades are negligible. At Atami, a tunnel five miles in length is being driven through the mountain, coming out at the other end at Numadzu. The work of driving the tunnel has now progressed about one mile from either end and as it is advancing at the rate of 8 feet per day, or about 0.5 mile per year, it is expected that within three or four years the tunnel will be completed and trains can be dispatched over this cut-off instead of over Gotemba. The effect of this will be to shorten the distance by about 7 miles and eliminate about 20 miles of heavy grade. The maximum grade on the present line is 2.5 per cent as compared with 0.88 per cent on the cut-off at the approaches to the tunnel, and the maximum elevation at Gotemba is 1600 feet above sea level as compared with 300 feet at the center of the tunnel. The tunnels on the cut-off have been constructed with sufficient head room to allow for the installation of trolley wire, and as the clearances on the present line are barely sufficient for the rolling stock, no attempt will be made to electrify this section until after the completion of the tunnel.

Running west from Numadzu, the next two engine divisions ending respectively at Hamamatsu (166.9 miles) and Ogaki (266.1 miles) are practically over water level grades. The country through which they pass is very fertile, rice being the most important crop but mulberries, tea, tobacco and other miscellaneous crops are grown where the soil or elevation are unfit for rice.

The next engine division from Ogaki to Kobe encounters a spur of the main mountain range of the island which runs southward and forms the Yamada or Ise peninsula. The main line therefore turns northward from Nagoya to cross these mountains through the somewhat lower level forming the pass at Maibara. There is a somewhat more direct line through the mountains from Nagoya to Osaka but the grades and curves are severe and as a consequence comparatively few and light trains run over that division. All heavy traffic is routed by way of Maibara, Kyoto and Osaka to Kobe (373 miles). All of the heavy trains

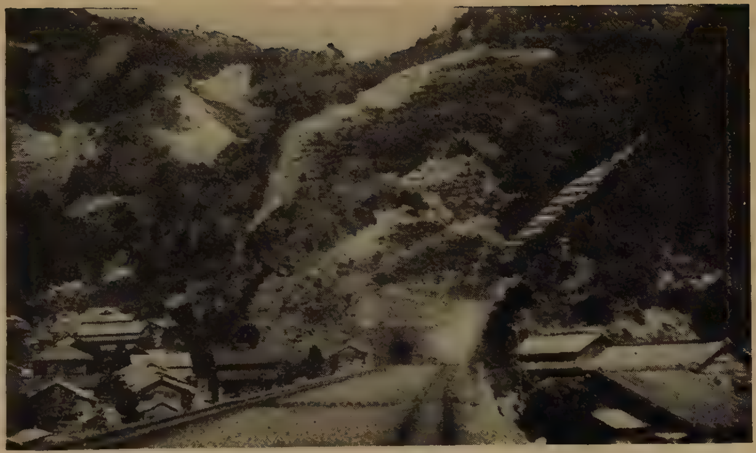


Fig. 5. Railroad Tunnel. Little steep sided spurs of hills are encountered which cannot be graded or cut and require tunnelling. In general, a total bore tunnel is used with brick lining throughout

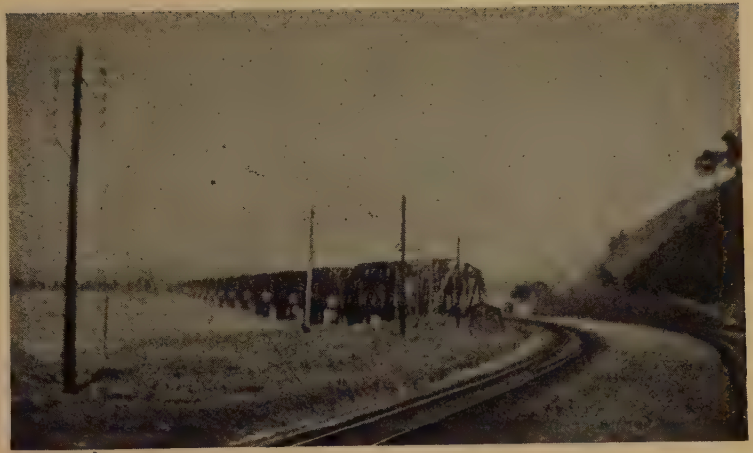


Fig. 6. Bridge over the Tenryu River. A through truss bridge with nineteen 200-ft. spans. A serious problem is presented by the wide variation in runoff of the rivers, which requires long bridges over river bottoms that are usually dry but at certain periods are roaring torrents

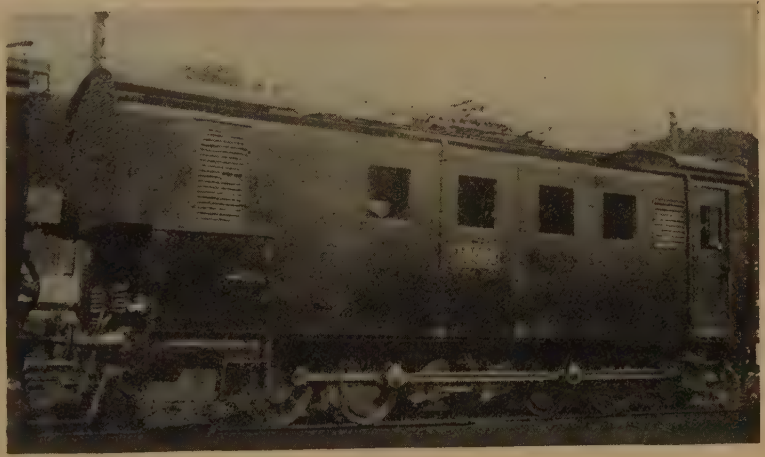


Fig. 7. Sixty-ton Electric Locomotive for the Shin Etsu Line. This locomotive was built in the shops of the Japanese Imperial Government Railways. It operates both on rack and adhesion, and is unique in that it is the heaviest locomotive in service on any electric rack railway

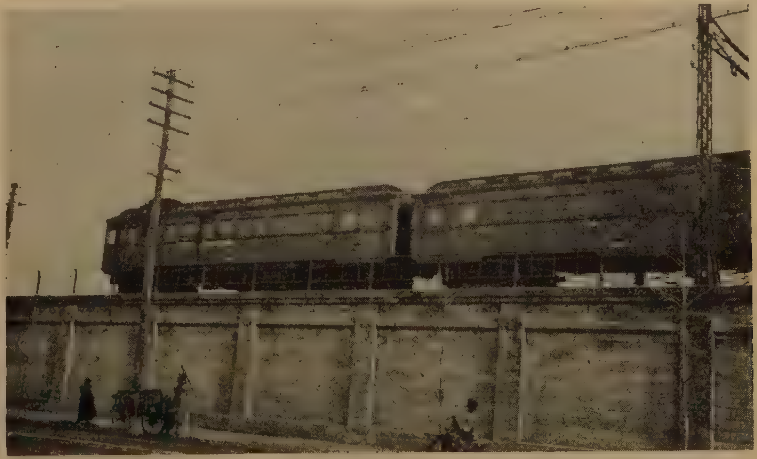


Fig. 8. Multiple-unit Train on the Viaduct Inside the City Limits of Yokohama

also have to take a pusher over the Maibara grade.

Kobe is the end of the Tokaido line and from here westward traffic is carried on the Sanyo line along the shore of the Inland Sea to Shimonoseki (702 miles from Tokyo). While the road follows the seashore, the rugged and broken character of the country makes numerous tunnels and cuts necessary. Even where in general the road runs through rice fields which means a water level grade, there are little steep-sided hills and spurs running down from the mountains which require deep cuts or short tunnels.

Roadbed

The road throughout is an example of the best class of construction. The track is well laid and stone ballasted. Cuts and fills are carefully graded and generally sowed with some sort of grass whose roots will hold the soil on the banks. One of the most difficult problems in all Japanese railroad construction is this of holding the bank. There is very little underlying solid bed rock. The soil is loose and friable and what rock there is seems to be very much shattered. The genius of the Japanese masons for building stone walls comes largely into evidence at every point. The splendid stone walls to be seen holding the embankments along the railroad tracks cannot fail to excite the admiration of the engineer. In addition to stone walls, the banks are liberally protected with cemented stone gutters or even concrete blocks inserted into the soil.

A serious problem which is presented to the Japanese engineer is the heavy periodic rainfall and its effect on the variation in run off of rivers and the construction of bridges. On this account, coupled with the absence of water storage either by natural or artificial reservoirs, the river valleys which at certain times are roaring floods are for a great part of the year wide flats of gravel and water washed pebbles. Such flats form convenient quarries for obtaining railway ballast which has only to be shoveled up, sifted and graded, but the wide valleys require bridging and the result is a number of long low multiple span bridges. The most striking of these bridges is that across the Tenryu River, 164 miles from Tokyo. This is a 19-span through truss bridge, 3900 feet in length. Long bridges of similar construction are encountered repeatedly along the lines of the railway.

The lines across the island all run through heavy grade sections. One of the most interesting of these is the Shin-Etsu line from Omiya to Niigata on the Japan Sea. As this line leaves the seacoast and approaches the high central country, it runs up a ravine from Yokokawa to Karuizawa for a distance of 7 miles. In order to make this ascent, it was necessary to lay the line out on a grade of $^1/_{15}$ or 6.66 per cent. Numerous side ravines empty into the main one with steep precipitous sides so that the line is a succession of tunnels, fills and bridges, there being 27 tunnels in the 7 miles. This section was laid out as a rack rail or cog wheel road with an Abt rack laid centrally between the running rails. The line was opened in 1893 and operated for several years with Abt steam locomotives. In 1912, it was electrified at 600 volts and 12 electric locomotives were furnished by the A. E. G. Company of Germany. Power is furnished from a third rail at the side of the track. During the war 12 additional rack locomotives were built by the Imperial Government Railways at their locomotive shops in Omiya and at the present time an additional order of locomotives is being furnished by European manufacturers.

Rolling Stock

Locomotive construction on the Japanese railroads is not standardized. As switch engines in the yards there are to be found a number of 040 and 060 locomotives as well as the American type or 440. Like other railroad systems they are using for yard work locomotives which have become obsolete for road service on account of increasing traffic. On the main lines, the Pacific type or 462 seems to be the favorite for passenger service and a number of Mallet locomotives are to be found on the heavy grade sections. All types of manufacturers are represented. English, German, Swiss and American locomotives are to be found but the Japanese are now building a number of locomotives in their own shops.

One of the interesting features that attracts the attention of an engineer is the one-handed shovel and the method of firing used by the Japanese firemen. Where an American fireman uses a two handed shovel and throws into his fire several shovels full of coal at one opening of the fire door, the Japanese fireman uses a shovel that carries not more than 10 pounds of coal and can be handled with one hand. This enables him to open the fire door with one hand while he throws a small quantity of coal on the fire. He thus obtains a more uniform and evenly distributed fire. One of the engineers of the railway service was authority for the statement that the Japanese locomotives are specified for a ratio of grate area to heating surface that enables them to avoid forcing their fire to the extent that is common in this country. Estimates made on the tonnage moved on the Japanese railroad system indicate that they move approximately 12,000 to 13,000 ton miles per ton of coal while records of railroads in the United States indicate that we move about 7000 to 8000 ton miles per ton of coal.

Japanese railroad cars are built to smaller dimensions than our own and are more economical in regard to dead weight per passenger carried. Third class and second class cars have longitudinal seats with a seating capacity of about 120 per car and ample aisles. They are consequently capable of carrying a very excessive load for rush hour and festival traffic. The seats themselves are generally about 3 inches lower than our own and the Japanese habits as well as dress lead passengers to a great extent to sit cross legged on the seats except when the cars are crowded. Second class sleeping cars have longitudinal single berths instead of the double berths to which we are accustomed. First class sleepers are compartment cars with upper and lower single berths in each compartment.

TABLE I

COMPARATIVE RAILROAD TRAFFIC—JAPAN AND UNITED STATES

	Japan	Per Cent	United States	Per Cent
Population	55,963,000		105,710,000	
Area square miles	148,756		3,026,789	
Population per square mile	376		35	
Railroad mileage	7,834		259,000	
Population per mile road	7,150		410	
Number of locomotives	3,300		69,000	
Miles of road per locomotive	2.37		3.75	
Ton miles per year per mile of road:				
Passenger trains	1,850,000	35	740,000	16
Freight trains	2,690,000	51	2,910,000	64
Locomotives	715,000	14	930,000	20
Total	5,255,000	100	4,580,000	100
Ton miles per year per locomotive	12,440,000		17,800,000	

For freight cars both double truck and single truck cars are in use but to a large extent the single truck small capacity freight car predominates. Of the 52,489 freight cars owned by the Government Railways in September, 1922, the average capacity was 11.77 long tons or 26,400 lb. The use of these small cars seems to be a natural development of the requirements of the traffic. The freight problem in Japan is not a long haul problem such as our roads encounter. It is essentially a short haul distribution problem, and as a consequence the small capacity car is better fitted to their service than the large capacity car with which we are familiar.

The couplers are of the European screw type. The use of this type is an inheritance from the early history of the railroads which were at first built under English supervision. On account of the evident advantages of the MCB automatic coupler as used in America, it is proposed to change to the automatic type. Large orders have already been placed for automatic couplers with the intention of using this as a standard in the future.

Train speeds are in general lower than our own. Comparing, for example, two crack trains on Japanese and American roads, we find that the Day Express train No. 1 runs from Tokyo to Kobe 373.5 miles in 11 hours and 45 minutes or 31.7 miles per hour. On the other hand, the Empire State Express on the New York Central runs from New York to Buffalo, a distance of 438 miles, in 9 hours, being a schedule speed of 49 miles per hour.

Traffic

The traffic on the Japanese lines is enormous as might be expected from the density of the population and the relatively low railroad mileage. Between Yokohama and

Tokyo, on the electric tracks five-car multiple unit trains are run from 5 a.m. to 1 a.m. During 18 hours of the day the train headway is 12 minutes. These five-car trains have a seating capacity of 600 passengers and during the rush hours a train may be carrying 1000 to 1200 passengers. During 1922, the question was seriously discussed of reducing the headway to 6 minutes in the rush hours of the day. On the other two tracks of the Tokaido line 44 steam passenger trains are scheduled daily to leave Tokyo station west bound. The same number arrive at Tokyo east bound. Besides the Tokaido line there are two other main lines leaving Tokyo: the Tohoku line on which 39 trains are scheduled daily and the Chuo Line with 13 trains.

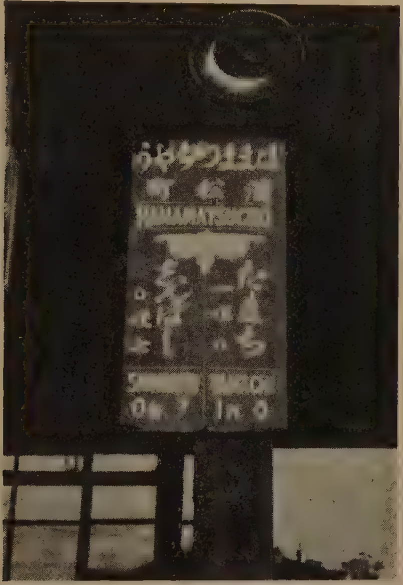


Fig. 9. Station Signboards. The name of the station is shown first in Japanese script; second, in Chinese characters; and finally, in English. Also the distances are indicated to neighboring stations

Fig. 10. Wayside Road Maps. Maps are to be found at many road crossings indicating location of highways, road, tracks, and points of interest in the neighborhood

The density of traffic not only over the suburban lines but over the whole railway system seems to be greater than the corresponding density of traffic in the United States. Table I illustrates this more clearly than can be done by any discussion. The table is based on the latest available statistics but the yearly variation in these will not affect the broad comparison intended.

The density of traffic as arrived at in the last lines of the table is admittedly approximate. It is obtained by taking the figures of annual passenger car miles, freight car miles and locomotive miles and multiplying each by weight of the average loaded car or locomotive and reducing this to ton miles per mile of road. It will show, however, in general terms, a comparison of the traffic of the two countries and the difference in the problem presented to the railroads. It shows, for example, that the Japanese roads are better equipped with rolling stock than ours, there being an average of one locomotive for every 2.37 miles of road, while in the United States there is one locomotive for every 3.75 miles of road. Passenger movement in Japan occupies 35 per cent of the train tonnage as compared with 16 per cent on the railroads in the United States. The actual passenger tonnage movement per mile of track is 250 per cent of that in the United States. The density of freight movement is about equal to that in the United States but it only represents 51 per cent of the total tonnage as compared with 64 per cent in the United States. The average service per locomotive in the United States is apparently 50 per cent more than in Japan, probably due to the greater weight of the average American locomotive and the greater tonnage of train hauled by it. A complete discussion of this subject would be

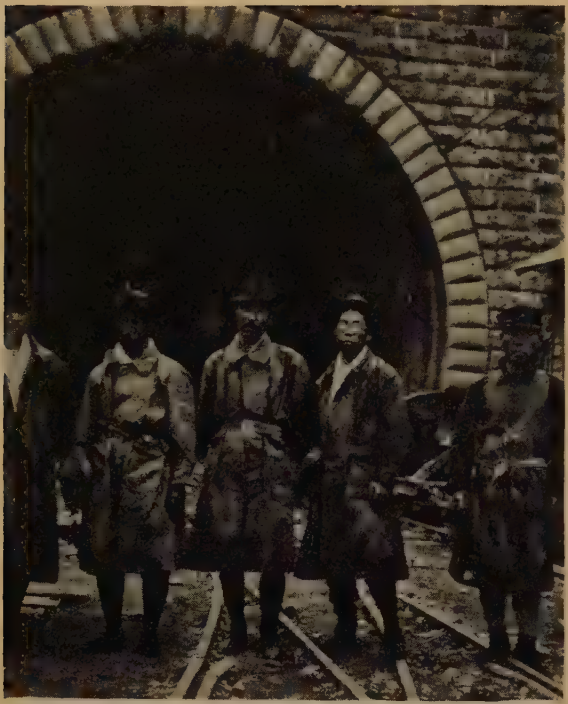


Fig. 11. Atami Tunnel, 5 miles in length and now being driven through the backbone of the Idzu Peninsula in the construction of a low-grade cutoff to avoid the grades of the Gatumba Pass

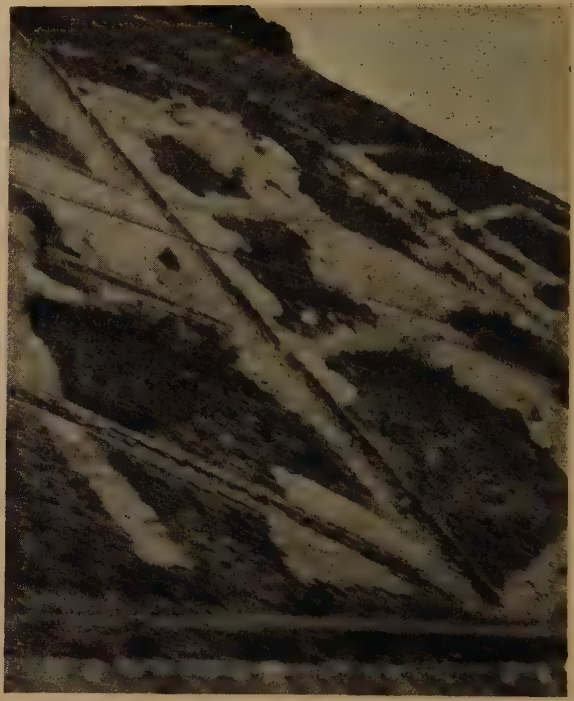


Fig. 12. Holding the Embankment at Kodzu. This side hill is protected with a stone wall at the foot with cemented stone gutters across the face of the hill and plates of concrete inserted into the loose soil

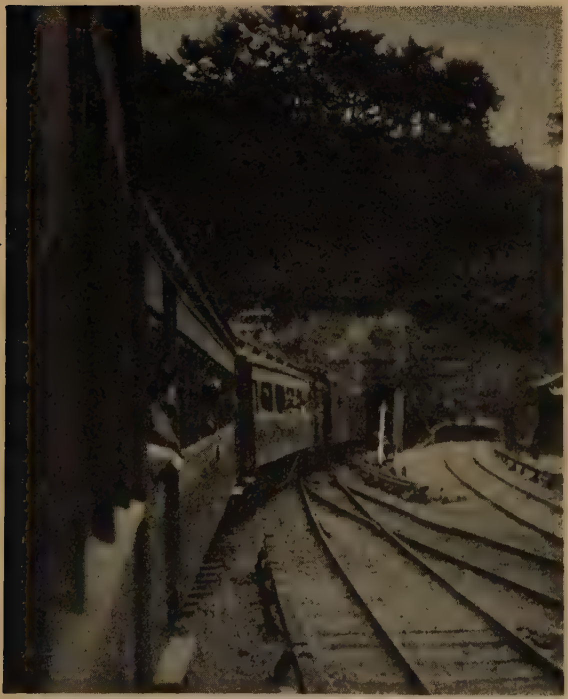


Fig. 13. Kumanotaira Station on the Electric Rack Rail Section of the Shinetsu Line. Seven miles of this line are built on a grade 6.66 per cent and have 27 tunnels. The maximum length of trains is fixed by the length of the only level section at Kumanotaira

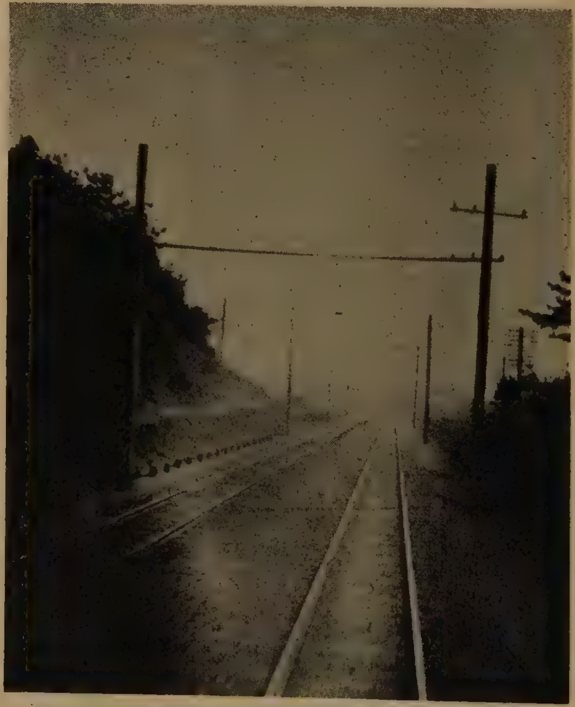


Fig. 14. Tangent Track Construction. On the main line outside the city wooden poles and a light bridge construction are being erected for the catenary

very interesting but would require more detailed statistics than the writer has at his command and would exceed the limits set to this article.

To the foreigner travelling in Japan, a feature which is interesting as well as helpful is the complete way in which information is available as to routes and distances. The time table issued by the Government Railways is a model of completeness. It gives schedules, distances, rates of fare and in connection with each time table shows a skeleton map indicating the principal stations and the connecting lines. At every station the signboard gives the name of the station in Chinese characters, in Japanese script, and in English. In addition the names of the next station in either direction and the distances to it are given below, with a hand pointing in either direction. Where neighboring roads lead to temples or other tourist resorts, a large scale map will be found on a signboard either at the station or at highway crossings indicating the famous places and the roads leading to them.

Rates of fare are distinctly less than in the United States. Since fares are arranged on a sliding scale, and vary with the class of service as well as with the length of trip, it is impossible to state comparative figures in one sentence; but the following schedule rates for a ride of 100 miles can be used as a fair comparison with rates in the United States.

Third class for 100-mile trip	$1.15
Second class for 100-mile trip	2.30
First class for 100-mile trip	3.45

In addition to this there is a charge for extra fare trains which makes the actual fare for a first class ride only a little less than in the United States.

Electrification

Several references have been made in the course of this article to the electrification of the railroad lines and it will therefore be of interest to give a sketch of the plans which had been made and approved for proceeding with this electrification. It must be borne in mind that these plans were previous to the disaster of September 1st, and that may have modified them to some extent.

The two underlying reasons for deciding on railway electrification were shortage of coal and congestion of traffic.

A fair quality of coal is mined in the islands of Kyushu and Hokkaido. These coal beds are limited in extent and will be exhausted within a reasonable time. Some surveys indicate that the accessible deposits will be exhausted within the next 80 years. The next source of coal supply is the Fushun collieries in Manchuria but the question of transportation will always be an outstanding objection to the use of this coal. On the other hand, there are ample water powers on the Japanese islands and these are rapidly being developed. The original hydro-electric developments were installed by small companies for relatively local power distribution. These have been gradually consolidated into larger corporations with increasing power voltage and range of transmission. There are at the present time two general systems of hydro-electric power production and transmission, one of which centers on Tokyo and Yokohama on the eastern side of the island while the other centers on Kobe and Osaka on the west. While neither of these systems is completely unified either in financial control or physical operation, they are gradually tending towards such a condition with a standard transmission voltage of 154,000 volts. According to the present plans, each of the two systems will within 10 years have an installed capacity of 1,000,000 kw. and with interchange of power between the two systems will form a super power system connecting the chief hydraulic centers with the principal industrial centers of the island.

Referring now to the second point, that of traffic congestion: there has been a rather intense controversy among engineers as to the best way of handling the present traffic and allowing for its continual increase. As has been shown in the previous pages, it is a fact that traffic is very heavy and it has long been evident that some method of handling more traffic over these lines must be found. The present track gauge is 42 inches. One party has strongly advocated increasing this to standard gauge, thereby giving an opportunity to install heavier motive power, heavier cars and to handle a greater traffic. This, however, would require relaying all track, rebuilding bridges and tunnels as well as rolling stock and would involve an almost prohibitive expense. As contrasted with this, electric operation of the present line would increase the speed of trains, would avoid delays at tunnels, and would eliminate much of the delays in freight yards. It would, therefore, result in the same increase of capacity at a vastly less expenditure. It has finally been decided to electrify the roads, maintaining the present gauge of track, to adopt 1500 volts d-c. as the standard system, and to proceed as rapidly as possible with the electrification of the principal lines.

The suburban lines around Tokyo are already operated electrically. The first of these lines to be electrically equipped was from Manseibashi to Nakanoa, distance of eight miles. This is the suburban section of the Chuo line and was put in operation in 1905. In 1910, the Yamate belt line was equipped for electric operation. This is a belt line running from Tokyo station through Shinagawa and around the north side of the city, making connections on the eastern side with the Tohoku line at Ueno station and at Akabane. This line was also equipped at 600 volts and the length involved was about 23 miles. In 1915, the Yokohama-Tokyo line was equipped for multiple-unit operation. On account of the length of the suburban run and the weight of trains it was decided to adopt 1200 volts for this electrification rather than 600 volts. The suburban lines in the city are still operated at 600 volts and the change over from 600 to 1200 is made just beyond Shinagawa station. With the adoption of 1500 volts as the standard railway voltage, there will be a change made in the voltages of these various lines. The Tokyo-Yokohama line will be considered a part of the main railway system and will be operated at 1500 volts. New motors and equipments will therefore be purchased for this line. The Chuo and Yamate lines which are now operated at 600 volts will be changed to 1200 volts utilizing the equipments of the Tokyo-Yokohama line and as far as possible parts of the present 600-volt equipment.

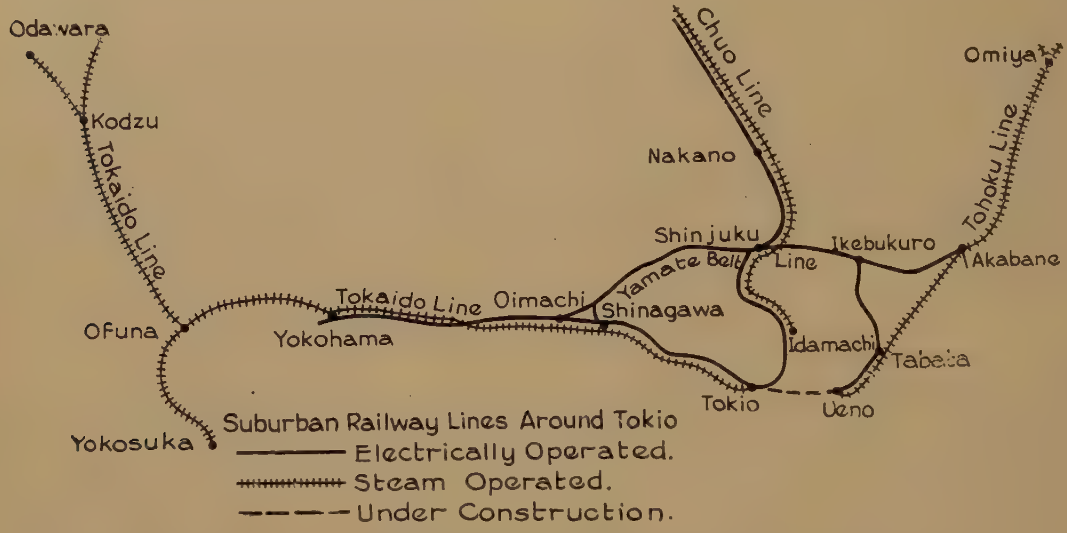


Fig. 15. Suburban Railway Lines Around Tokyo. Within one or two years all these lines will be electrified. The road will be four-track as far as Ofuna Junction and multiple-unit trains will run to Yokosuka

The city of Tokyo proper has a population of about three million, but the transportation facilities are less than for any other city of similar size. Paris, which has a population of the same amount, has 1020 miles of street railways, while Tokyo has only 180 miles. For a growing modern city, the street railway system is utterly inadequate and the extension of its rapid transit facilities has been the subject of much discussion and investigation. Plans have been drawn for the construction of a number of subways under the city streets. Without detailing the names of the different companies which have applied for franchises for the construction of such subways, it is sufficient to say that plans have been made for a number of different lines. In general, they all reach the center of the city near Tokyo station and the aggregate makes a system of ten subways radiating out from this point. Due to the fact that Tokyo is in an earthquake zone, the effect of earthquakes on such underground structures has been the subject of discussion among Japanese engineers. The consensus of opinion was that underground structures could be built to stand earthquake shocks as well or better than surface structures. These conclusions may be subject to modification after the experiences of September 1st. At least, the experience of that date should give valuable data on the question of desirability of subway construction.

The first section of the Tokaido line to be electrically equipped will be the 50 miles running from Tokyo westward and ending at Odawara. Electrical construction and installation were proceeding along this line during the early part of 1923, and it was expected that by the spring of 1924, steam operation would be eliminated from this 50-mile section and all train movements would be carried out with multiple unit cars or electric locomotives.

The next section to be equipped will begin from Akashi, the terminus of the engine division 10 miles west of Kobe and 385 miles from Tokyo. This will include the electrification of the suburban lines around Kobe and toward Osaka and Kyoto. This section is selected on account of the heavy traffic centering in and around these cities.

After this, successive sections will be equipped, working eastwardly at such a rate that by 1928 the whole line will be under electric operation from Akashi to Numadzu. By 1928, the Atami tunnel will be completed and the electric equipment of the Tokaido line can be completed by joining Numadzu to Odawara through the Atami cut-off. At the present time there are about 600 steam locomotives assigned to this line and to replace this steam equipment, electric locomotives will be purchased in successive years in order to fill approximately the following schedule:

1923	28 electric locomotives
1924	38 electric locomotives
1925	48 electric locomotives
1926	76 electric locomotives
1927	73 electric locomotives
1928	73 electric locomotives
Total	336

Of this total number, 42 locomotives have already been contracted for and in part delivered. Purchase of additional locomotives will, however, be delayed until sometime in 1925.

Referring now to trolley and overhead construction, a very substantial type has been selected and is being installed. The standard type of overhead construction consists of steel poles either latticed or tubular with a light bridge supporting the catenary. Where wood poles have been installed, it is admittedly only for temporary use on account of the expected relocation of tracks or other similar changes. The Japanese engineers have adopted throughout for both transmission and distribution lines the best types of construction and the work of their track gangs and linemen has resulted in a very handsome and permanent structure.

The extent to which railway electrification will be finally adopted it is impossible to say at the present time. The committee for investigating this subject has already designated 2000 miles of railroad as suitable for electrification, selecting particularly those sections where heavy grades or tunnels, heavy suburban traffic, available electric power, or other conditions make steam operation difficult or emphasize the advantages of electrification. There is now under construction in Tokyo a short piece of elevated road connecting the main Tokyo station with Ueno station on the Tohoku Line. When this is completed there will be direct physical connection between the Tokaido and Tohoku lines and through trains can be dispatched through the city of Tokyo from one line to the other. This will require a main central station in Tokyo from which all trains can be dispatched over both lines and will eliminate the delays now incident to transferring from one station to the other.

While it is improbable that the Imperial Government Railways would be justified in electrifying all the lines of its system, it is very probable that within a reasonably few years, we shall see main lines electrified on such a general and consistent scale that the system will present an example of the advantages of railway electrification that will well repay the study of the railway engineer.

Thomas A. Edison

THE INVENTOR AND SCIENTIST

By John R. Hewett

Editor, General Electric Review

This article was prepared at the request of Dr. Arnold Berliner for publication in *Die Naturwissenschaften*, but as there are so many of our readers who are naturally interested in Mr. Edison's life and work. we also publish it in the Review. Mr. Edison personally read through the manuscript and expressed his pleasure and appreciation.—Editor.

When the writer was asked to prepare an article on Thomas A. Edison—the scientist—he promptly said that Edison was a great inventor but not a scientist. Even if by juggling with words you could make some people believe he was a scientist what useful purpose would be served? Would the man whose name is a household word, not alone in America but throughout the world, as all that typifies originality, resourcefulness and inventive genius, wish to be called a scientist? The writer felt that he might rather detract from Edison's fame than add to it by calling the arch-inventor names.

So much has been said about Edison and his work; and enthusiasm and romance have so often exceeded the truth in unauthorized statements, said to have come from his own lips, that the gross exaggerations of the improperly informed have, unfortunately, often led to underestimation of his great achievements by more cautious people.

Edison's life has been full of such extraordinary activities and his work has been of such inestimable value to the world that it is impossible in a short article to give the reader a true perspective of what he has done. It is specially difficult to show what he has done in the realm of pure science, for his whole life has been spent in applying science to industry. During his entire career his scientific discoveries have always been a mere by-product of his inventions; and, for this reason, in the intense rush of productive work, have often remained unrecorded. But his intense energy and mental vigor have been so completely consecrated to work—unending work—that even if we go as far as to admit that his useful accomplishments have been 99 per cent in the realm of applied science and only 1 per cent in pure science—this 1 per cent of so large a total is a substantial contribution to the scientific world.

Because Edison's methods of work have been so different from others, many have been led to believe that they were not scientific—the truth is that Edison's methods of attacking and solving a problem are really scientific methods. And as it is not until people understand the difference in Edison's life, his training, and his environment, as compared with those of most men who have devoted their lives to technical and scientific pursuits, the author finds it necessary to devote a large portion of this article to showing these differences and the nature of Edison's work.

The dictionary definition of Science is: "Knowledge gained and verified by exact observation and correct thinking, especially as methodically formulated and arranged in a rational system."

It would be quite impossible to write a better or more accurate definition of Mr. Edison's methods.

If Mr. Edison's mode of work so exactly fits the definition of Science—why is it that we have not classified him among our scientific men? The answer to this question can only be found after we recognize that Mr. Edison's methods are so different from others—his work so original and his personality so exceptional that he cannot be classified. Although his methods are truly scientific they are not classical—they are original. A thousand scientists may be produced in a generation, but only one Edison.

Kelvin, Raleigh, Crookes, Lodge, J. J. Thomson, Rutherford and many other notable physicists and scientists did their remarkable work contemporaneously with Edison. The world heralds all of them as mighty scientists and men of unusual genius. They have all made valuable contributions to our knowledge. So has Edison made valuable contributions to our knowledge; and he, in addition, has laid the foundations for mighty industries that have added untold blessings and comforts to the lives of men. Yet Edison is not one of these great physicists and not one of them is an Edison. They differ in education, in training, method of work, and environment.

Most great scientists have had a classical education and are proficient mathematicians.

Although Edison's mother was a teacher and her influence over him was powerful and lasting, all the regular scholastic instruction he enjoyed was three months at the public school at Port Huron. He never was a mathematician—but with his original philosophy he reasoned: "I can always hire some mathematicians, but they can't hire me."

The mathematician absorbs—the inventor originates—and when we have these two high gifts, the mathematical mind and the power to originate, combined in one brain we have what the world is pleased to acknowledge as a great scientist or philosopher. And here Edison again is unique—he is a great scientific inventor without the aid of mathematics. This compels him to use methods of his own and they are so effective and productive that one of his favorite pastimes is to do things that his more classical confreres have pronounced impossible.

Most classical scientists have received their education and instruction at great seats of learning, have had the association of brilliant minds, the use of excellent equipment and have devoted years of their life to study alone. But this was not the way with young Edison. He experimented before he could read and earned money while he worked and educated himself. And how delicious some of his very first experiments were!

At the age of six he saw a goose sitting on her eggs—and noted the results. Soon after this observation Edison was missing and after a prolonged search was found in the barn sitting on a nest of his own construction filled with goose eggs and hens' eggs! Another experiment of his a few years later, when he was about ten years old, surely betrays the inquisitiveness of the scientific mind. He induced a lad to swallow large quantities of Seidlitz powder in the firm belief that the gas generated would enable him to fly. The result was convincing.

In place of learned companionship and the association of brilliant minds he gained his contact with the work and thoughts of others by omnivorous reading and rubbing shoulders with the rough world. He sold papers on trains, not because his people were poor, but, because it enabled him to buy chemical apparatus and materials and to purchase books, magazines and newspapers to further his studies.

His method of reading was as distinct from others as day is from night. We are told that when he, as a boy, gained access to a library he would boldly attack a whole section and read book after book irrespective of subject!

Even the boy Edison was characterized as "tearing the heart out of a book." He read prodigiously and remembered all that was useful. It is said of him that he never read or heard a statement without wanting to verify it by experiment. This was a genuinely scientific attitude toward life.

In place of the great and costly equipment that some men have been privileged to use in their training, Edison's equipment was made by himself. He gleaned the town for bottles, spent his earnings in filling them with chemicals, and labeled them one and all—200 odd bottles—"Poison"—irrespective of their contents, to prevent others interfering with them. His first laboratory was in his mother's cellar and he had to use all his powers of persuasion for it to be permitted to stay there. His second laboratory was the disused smoker, disused because unventilated, on the train on which he sold papers.

Here one of the calamities of his young life was the upsetting of some phosphorus because of the lurching of the train. This accident set the train on fire and he and his belongings were bundled off the train at a wayside station. It was on this occasion that he received so sound a box on the ears by the conductor that his hearing was permanently damaged. But Edison has always taken this hurt philosophically. This all happened when Edison was a mere kid.

It was while Edison was a newspaper boy that he became interested in electricity. He had become familiar with the railway telegraph. Batteries were expensive, so he tried to operate the telegraph system he had made of stovepipe wire, bottle-insulators, magnet wire insulated with rags, and spring brass keys with frictional electricity. He had no frictional machine so he used the family cat. The chief objection was that the cat, lacking Edison's enthusiasm for science, objected to the violent rubbing process and could run faster than Edison!

For some years after Edison left home he spent many arduous years in the central west as a telegraph operator. He traveled from place to place to wherever he could find work, and during all this time he never ceased experimenting whenever he could make the opportunity. He worked night and day. His chief object in working was to earn money so that he could continue his unceasing questions to Nature in the form of experiments and get her answers in the results he obtained. There is no better example to be found of knowledge gained and verified by observation than this period of his life reveals.

Each time Edison earned money, all except that needed for a bare existence was spent in research and experiments.

Edison's first great triumph as an inventor was his invention of the stock ticker which netted him $40,000. He had anticipated asking from three to five thousand, but asked General Lefferts to make an offer. When $40,000 was proposed Edison says: "This caused me to be as near to fainting as I ever got. I was afraid he would hear my heart beat."

This money enabled Edison definitely to start his spectacular career as an inventor and much of it was spent on his now famous inventions, the automatic, duplex and quadruplex telegraph. Jay Gould paid $30,000 for his interest in the quadruplex telegraph. This money was again spent in experimenting, and, among many things, much of it went in developing Edison's epoch-making inventions in connection with the telephone, motorgraph and microphone. From his work on the telephone he got his now famous "telephone money" receiving $100,000 for his carbon transmitter. To tell this interesting story in Edison's own words, when he was offered the $100,000, he said: "All right. It is yours on one condition and that is you do not pay it all at once but pay me at the rate of $6000 per year for 17 years." (The life of the patent.) "My ambition was four times too much for my business capacity and I knew that I would soon spend this money experimenting if I got it all at once so I fixed it that I could not. I saved 17 years of worry by this stroke."

A short time after this Edison received a similar amount on the same terms, for his chalk relay, which so effectively upset the dominant combination claim of Page. So for a period of 17 years Edison was receiving $12,000 a year from the Western Union Telegraph Company.

Edison spent all his money on experimenting and part of it gave us the phonograph, an invention that caused his name to be heralded throughout the world. Contrary to common belief, the phonograph did not owe its inception to Edison's pricking his finger with a point connected to a telephone diaphragm, but was the product of pure reasoning, the deduction being made from his experimenting with an automatic telegraph which embossed dots and dashes on a strip of paper. Edison observed that a musical note was produced when the strip was run under the point. A memo from one page of a historic notebook is dated 1877 and reads as follows: "Just tried experimenting with a diaphragm having an embossing point and held against paraffin paper moving rapidly. The strong vibration was indented nicely and there is no doubt that I shall be able to store up and reproduce automatically at any future time the human voice perfectly."

Some of Edison's greatest works overlapped and while he was still working on the phonograph he was studying the most fascinating problem of the age, the Electric Light.

The first gas company had been organized for commercial lighting in London as early as 1804, but grease and oil were still the common basis of illuminants and the great American whaling fleet was the source of America's supply of oil up to and beyond the middle of the nineteenth century.

In the year 1809 Sir Humphry Davy had shown at the Royal Institution an intense arc between strips of carbon, the source of electric energy being a battery of 2000 cells. In 1885 Faraday projected intense beams of electric light from voltaic arcs from the beacons of South Foreland and Dungeness across the waters of the Straits of Dover.

From 1850 onward the arc lamp and the dynamo developed rapidly and by 1878 the arc lighting industry was recognized as a reality.

To get a correct perspective of Edison's work, these and many other important events must be remembered and it should be borne in mind that the scientific world of this period was agog with excitement at the possibilities of electric light.

In the beginning of this new era of lighting the *modus operandi* was based on the consumption of something—commonly carbon—in a lamp open to the air. Every lamp the world had ever seen did this. Edison began by experimenting with lamps of this same type and it is said that he anticipated the flaming arc in 1875.

In the study of the lighting problem he became convinced that the lighting of houses and enclosed areas was the great field for artificial light and that the commercially successful system must include everything that a gas system included. An intense study of the problem convinced him that a successful electric light for this purpose must be a unit that gave light by incandescence.

Edison was familiar with the work of numerous other inventors in trying to produce an electric incandescent lamp, but all the work that had been done prior to 1877, when he began his experiments, was commercially unsuccessful. Many of the leading electricians, physicists and experts who had been studying the subject for a quarter of a century, had proved mathematically and by close reasoning to their own satisfaction that the subdivision of the electric light was impossible.

Edison never assumed to be a pure scientist or philosopher, and, also, he never let himself be bound by the opinions or assertions or proofs of others. There are, indeed, few better examples of a scientific way of approaching a subject and finding the solution to a world-baffling problem than the methods Edison employed in giving us the first commercially successful electric incandescent lamp. After innumerable experiments had been tried in a host of different directions, Edison decided that the solution of the problem of subdividing the electric light, or rather subdividing the electric circuit, lay in the production of an incandescent lamp of high resistance with a small radiating surface.

The work he did in solving this problem took years and could only be fully described in many volumes. To find a suitable material for his filament he carbonized over 6000 different forms of vegetable growth and had spent $40,000 before he produced a filament that would burn for forty hours.

Edison sealed his filament into a hermetically closed globe of glass, so that he could retain his vacuum, and it should interest all scientists who know something about the production of modern electric lamps and those younger children of science—the many forms of electron tubes or valves—to learn that Edison knew the value of a high vacuum and the advantage to be gained by heating his filament as the bulb was being exhausted. At this early stage he learned, through experiment, a great deal about the effect of residual gases.

It is said that no one ever saw Edison in a hurry or ever saw him lazy. . His interest in a problem never seems to diminish and his enthusiasm never wavers no matter whether his experiments on one problem last for six months or six years. It needed a genius with these gifts to solve the problem of electric lighting, as the lamp was only one detail, an important detail it is true, but still only one of many in the invention and development of a commercially successful electric lighting system.

To Edison's intensely practical mind the problem was to produce an electric light system that could compete with, and win out against, a gas system. To accomplish this purpose he studied the gas system and it is said that Edison knew more about the generation, distribution and use of gas than any other man of his time.

The research that Edison did in evolving his complete system of lighting entailed an amount of work that is almost impossible to realize. Some idea of the magnitude of this undertaking may be gained from the statement that between the years 1880 and 1908 he took out no less than 375 patents in connection with this work. Of these 149 were on incandescent lamps and their manufacture, 77 on distributing systems and their control and regulation, 106 on dynamo electric machines and their accessories and 43 on minor items such as switches, sockets, safety catches, meters, etc.

Among this host special attention should be called to his inventions of the feeder and three-wire system.

It is necessary to pass over the large amount of work Edison did on his electric railway with the bare statement that while he was still over-busy with the development of his incandescent lamp he built an electric railway at Menlo Park with motor, control, power supply and everything complete, all of his own design, and that this electric railroad carried both passengers and freight.

And again, while still busy on the development of his lighting system, Edison undertook and brought to a triumphal conclusion the most colossal experiment in separating magnetically low grade iron ore. Between the years 1880 and 1885 he carried out experiments without number, which a few years later resulted in his building a plant that was the wonder of the world to tear down mountains containing only one-fifth to one-fourth of magnetic iron.

Every item of this gigantic plant for crushing the rock was designed by himself, and his giant rolls staggered the imagination of men accustomed to the mighty machines used for doing this work and many stood dumb with amazement as they watched Edison's giants doing their fabulous work and saw great rocks weighing over one half a ton thrown from 20 to 25 feet in the air in the process of crushing.

It has just been stated that Edison brought this work to a triumphful success. So he did. But, alas, it was a gigantic failure as well as a splendid success. The success was due to Edison. The failure due to the discovery of rich iron ore in the Mesaba Range in Minnesota that could be cheaply mined and cheaply marketed, a circumstance over which the creator of this mighty plant, which would have founded a great industry, had no control.

The Minnesota discovery brought the price of iron ore down from $6.50 to $3.50 per ton. So great a blow as having to abandon this huge plant just after completion, which had taken five years of unremitting toil, would have stunned most men—Edison had spent most of his own money in this project and the enterprise was heavily in debt. When the decision was reached that the plant should be abandoned, because it could never be a commercial success, Edison took the next train home to Orange.

Edison had always paid his debts and on this memorable journey to Orange he laid his plans to pay off this heavy burden. He was determined that no one else should suffer through the failure of his scheme. He figured the possibilities of paying this debt with the profits on his phonograph business and found it impossible. So on this short journey he came to a remarkable decision, which is so characteristic of the man that it must be recorded. The world knows the fruits of this decision but not the romance of how it was arrived at. He decided to develop a storage battery and to use the experience he had gained in building and operating his ore concentrating plant in starting the manufacture of Portland cement. He did.

He planned his Portland cement factory himself and in doing so set aside all precedents in an old established industry. He "butted in" with new ideas and new methods and built a cement plant that produced cement on a gigantic scale and at a lower cost than any plant then in existence.

Concurrently with building up a successful cement business he started his marvelous series of experiments in producing a new and better storage battery. His mental attitude in starting on this new quest is well described in his own language to a friend: "I did not think Nature would be so unkind as to withhold the secret of a good storage battery if a real earnest hunt were made for it." And when the job was done he attributed his success to "hard work based on hard thinking."

Edison used his own methods on this invention that was truly scientific in its character and tremendous in its scope. We are told that the first two or three thousand experiments were tried in connection with the use of copper oxide as an element in a new storage battery, but that it offered no advantages.

After prolonged investigations he discovered a series of reactions between nickel and iron which showed great promise. But between this discovery and the completion of the task Edison probably made close on to 50,000 experiments.

Much the same story might be told of the innumerable experiments he carried out in perfecting his motion picture machine and other inventions of his too numerous to mention.

With this brief sketch of some of Edison's work and world known achievements there is no doubt that Edison is a great inventor and a great engineer. But is he a great scientist? He has built mighty industries that have added more to human comfort and happiness than man can record and he has only accomplished this by applying to industry the knowledge he gained and verified by exact observation. So are not his scientific accomplishments enormous? He is a great scientist—but a greater inventor—he did not work in the realm of pure science for the sake of getting results that were of scientific interest only. But he is the greatest exponent of industrial research that we have ever seen; and, as his chief object was to apply science to industry, the work he did that is of more interest to science than to industry has always been overshadowed by the work he did in applied science.

It is interesting now to see where some of the by-products of Edison's versatile imagination and intense inventive genius have been of as great, or of greater, interest to science than to industry. It is only possible to give a few examples.

The scientific by-products of Edison's work in commercializing incandescent lamps have been very valuable in many directions.

He supported his filament on platinum wires which were sealed into the glass and he made the whole structure of his globe glass so that it could be hermetically sealed to retain the vacuum. This work established valuable principles which scientists have used extensively. In a Smithsonian publication entitled "The History of Light," by Henry Schroeder, this particular contribution of Edison's is described as follows:

"After several trials he finally was able to carbonize a piece of ordinary sewing thread. This he mounted in a one-piece all glass globe, all joints fused by melting the glass together, which he considered was essential in order to maintain the high vacuum. Platinum wires were fused in the glass to connect the carbonized thread inside the bulb with the circuit outside as platinum has the same coefficient of expansion as glass and hence maintains an air-tight joint. He reasoned that there would be occluded gases in the carbonized thread which would immediately burn up if the slightest trace of oxygen were present, so he heated the lamp while it was still on the exhaust pump after a high degree of vacuum had been obtained. This was accomplished by passing a small amount of current through the 'filament' as he called it, gently heating it. Immediately the gases started coming out, and it took eight hours more on the pump before they stopped. The lamp was then sealed and ready for trial."

In 1879 Edison sent a communication to the American Association for the Advancement of Science "On the Phenomena of Heating Metals in Vacua by Means of an Electric Current." This communication was published in the Proceedings of the Society (28th meeting) in the year 1879.

Edison, in discovering the value of heating his filaments while drawing the vacuum in his lamps and in noting the effect of residual gases, paved the way for much modern work which has borne marvelous results.

In studying the "blackening of the globe" he noted the Edison Effect. The story of how he communicated this fact to William (afterwards Sir William) Preece and how he (Sir William) reported it to the Royal Society of London in 1884 and the results which followed are so ably told by Clayton H. Sharp in the January, 1922, issue of the *Journal of the A.I.E.E.* that it is only necessary here to give the barest outline.

Edison not only noted the blackening of the globe by a "discharge" from the filament but actually introduced another element in the form of a wire or plate into the lamp and connected this, through a galvanometer, to the positive terminal of the lamp. The whole world now knows how Professor J. A. Fleming carried on the investigation of the Edison Effect from this point and produced his wireless detector from these general principles and how DeForest took the next great step by introducing the grid between the filament and the plate and thus gave us the forerunner for our modern wireless valve.

The truly remarkable work that Langmuir did in the production of electron tubes so stable as the kenotron and pliotron was all that remained to turn the Effect noted by Edison into one of the greatest discoveries of the age. So Edison in noting the Edison Effect made a great contribution to pure science.

Edison's work on the telephone, and especially the invention of his carbon transmitter, is not only of scientific interest but of both practical and scientific value; in recognizing the inherent faults in a make and break method and substituting therefor a device employing carbon particles, which in reality constituted a valve principle, wherein the resistance and, therefore, the current, could be varied by changes in pressure, he gave us a great improvement in one of the most useful of modern inventions—an improvement which immediately rendered the broad invention of the telephone a practical and commercial success. This was a great scientific achievement.

Edison's invention of the phonograph, whereby human speech and all manner of music and noises of all description can be stored on inanimate disks or cylinders, and be reproduced at will innumerable times, and reserved for future ages, is one of the scientific wonders of the last century. This discovery is in the realm of science and the uses of the devices that can be, and have been, made by virtue of this discovery are of real scientific import as well as of great popular value. Edison's researches in the field of acoustics to perfect his talking machine covered a wide field.

Edison's scientific investigations in the realm of electro-chemistry, in connection with the invention and development of his storage battery, led to the discovery of chemical combinations which would permit the making of a successful storage battery with an alkaline electrolyte; by no means a small scientific achievement. Further, he succeeded in discovering a chemical action that is so nearly absolutely reversible that there is no or little loss or disintegration of the materials used.

Another scientific disclosure of Edison's well worthy of mention is his discovery of the change in friction when porous materials are moistened with electrolytes and passed between electrodes. He used this discovery in making loud speaking telephones. An exhibit of this invention was made at the Paris Exhibition in 1881.

Edison was the first to discover that tungstate of calcium was very sensitive in fluorescing to X-rays. He applied this discovery in making his fluoroscope. Further in this same direction he investigated upwards of 400 minerals and 5600 crystalline salts and mixtures to determine their fluorescence to X-rays and found that all crystals of organic salts containing the benzol nucleus will fluoresce to X-rays.

Clayton H. Sharp, in the same article already referred to, touches on Edison's work in developing systems of communication without wires and Edison's discovery of "Etheric Forces," but this story is too long to enter into now. It ought to be more fully described at some future date.

Edison's contributions to science are by no means small but his contributions to applied science are far greater. No man has excelled Edison in his ability to eliminate technical difficulty in applying scientific principles to industry.

Much of the scientific work Edison has done will never be known because it has never been recorded. He was never primarily interested in science for the sake of science and he made no investigations in the realm of pure science which were disconnected with his inventions.

Edison has had all his life an incalculable capacity for work and an unsurpassed inventive ability. He is a man of keen reasoning power and tenacious memory and these high gifts have been applied, during a most marvelously active life, to giving the world new devices and new industries.

In writing the present article the author has, by permission, made free use of the material in that excellent book "Edison, His Life and Inventions," by F. L. Dyer and T. C. Martin; and has received much help from notes given him by Mr. Edison personally and by conversation with him.

Internal Friction Theory of Shaft Whirling

By A. L. Kimball, Jr.

Research Laboratory, General Electric Company

In our March issue we published an article on shaft whipping by Dr. B. L. Newkirk, in which he analyzed the disturbances in shafts due to whipping and showed means for preventing these. Our present contribution shows Mr. Kimball's theory of internal friction in shafts as the cause of whirling. He shows that the internal friction due to bending may cause a shaft to whirl when rotating at any speed above the first critical speed.—Editor.

Introduction

The object of this article is to show that for a revolving shaft a disturbing force must exist due to an internal friction or viscous action in the shaft itself under certain conditions, and that if this disturbing force is great enough, a whirling of the shaft must result. This whirling should be of a frequency equal to the resonant frequency of the shaft, being independent of the speed of shaft rotation. The disturbing force can produce whirling, however, only when the rotational speed of the shaft is above its resonant frequency, or when the shaft is running at a speed above its first critical speed, otherwise the disturbing force is negative, and a whirling of resonant frequency will be damped instead of sustained.

The work described in this article is a contribution by the writer to an investigation of shaft whipping and whirling by Dr. B. L. Newkirk of the Research Laboratory.

Illustration of Action of Disturbing Force

This can perhaps be shown best by considering a shaft carrying a flywheel and deflected under gravity (see Fig. 1). Assume the shaft to be rotating in a clockwise direction. Fig. 2 and Fig. 3 show end views of this rotating shaft. In one case the shaft is assumed to be purely elastic with no internal friction of any sort. In this case the plane of deflection is vertically downwards as shown in Fig. 2. In Fig. 3 is shown what happens when, besides the elastic restoring force, the shaft has an internal friction which introduces a damping action as the shaft progressively bends due to its rotation. In this case the flywheel is deflected sideways through a small angle ϕ. Fig. 4 shows how the magnitude of the disturbing couple may be measured, as it must just balance the gravity couple shown.

A simple way of illustrating this effect by experiment is to make up a shaft of some substance which is very viscous, and the elasticity of which is practically zero. Molasses candy of the right consistency will serve. If a shaft of this substance is suspended at its two ends in the fingers it will rapidly assume a sag. If it is given a twist, however, the sag will be thrown in the direction of twist as shown in Fig. 3.

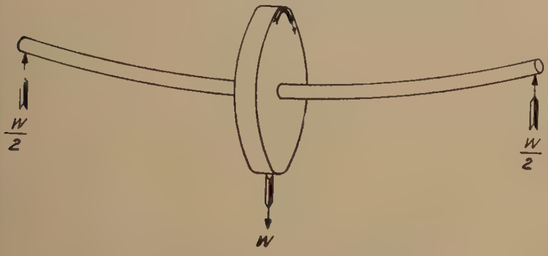


Fig. 1. Side View of Rotating Shaft and Flywheel Deflected by Gravitation

Explanation of Action of Disturbing Force

Perhaps the most general way of looking at this is from the energy viewpoint. If we consider a rotating shaft deflected as shown in Fig. 1, every part of it must go through a cycle of extension and compression, except the fibers at the center. If all parts of the shaft are purely elastic, there will be no hysteresis action and no heat dissipation. There will, therefore, be no expenditure of energy due to the extension and compression of its different parts as the shaft rotates. On the other hand, if besides the elastic reaction, there is frictional resistance during extension and compression in any part of the shaft shown in Fig. 1, there must exist a corresponding hysteresis effect and energy will be expended, causing a heating of the shaft. This energy must evidently be supplied from the applied torque. Now there has to be a reacting torque acting against the applied torque to produce the heating. This must come in some way from the gravitational deflecting force which causes the deflection because no other external force exists other than the applied torque under the conditions of the problem. The only way the gravitational force can produce such a reaction is through a forward inclination ϕ of the plane of deflection, Fig. 3. The shaft swings forwards until the reacting couple reaches the required value, Fig. 4.

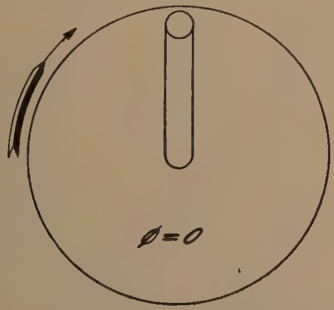


Fig. 2. End View with No Internal Friction

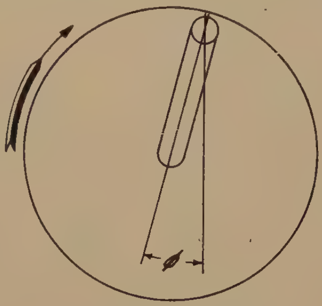


Fig. 3. End View with Internal Friction showing Deflection Effect

Another way to see how this force arises is to note that all the fibers on the front side of the shaft of Fig. 1, as they move from the bottom to the top of the shaft are shortening, while as they move from the top to the bottom they are lengthening. Since internal friction produces a compression stress on shortening fibers and a tension stress on lengthening fibers, the shaft will tend to spring forwards due to internal friction stresses just the way it tends to spring upwards, due to the elastic compression at the top and the elastic tension at the bottom. Internal friction stress depends upon the *rate of change* of extension or compression of the fibers and elastic stress depends upon the *amount* of extension or

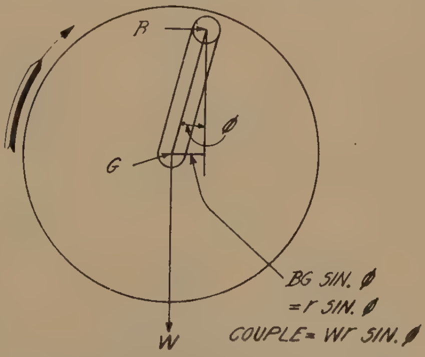


Fig. 4. Magnitude of Deflecting Couple

compression of the fibers. The two must be clearly differentiated. The reactions from these two causes are 90 degrees apart with reference to the shaft circumference. It is this transverse force arising from the internal friction forces which causes the deflection ϕ shown in Fig. 3, and which may produce whirling.

Production of Whirling

It has been shown that the disturbing force caused by internal friction due to the rotation of a deflected shaft, as shown in Fig. 1, will produce a couple tending to throw the plane of deflection forwards in the direction of rotation. When the deflecting force is gravitation, this couple is balanced as soon as the deflection ϕ is reached, Fig. 4. Suppose the shaft to be set on end, however, and suppose the deflection to be due to centrifugal force as shown in Fig. 5. In the first place, the plane of deflection of the shaft revolves or *whirls* carrying the flywheel around with it. The deflection is maintained by the centrifugal force $W\omega^2 r$ shown in Fig. 5. Furthermore, this motion has a characteristic period or a resonant period at which whirling is readily built up, known as the critical frequency. This frequency is, of course, determined by the stiffness of the shaft and mass of the rotor. Therefore, if we suppose that there exists a deflection due to centrifugal force, as already mentioned, we must suppose the plane of deflection to be revolving at this natural whirling frequency. Having pictured the deflected shaft of Fig. 5, whirling at its resonant period, what are the conditions necessary for the existence of the couple due to internal friction which must be continually urging the shaft forwards to maintain the whirling? There must be some force to maintain it, otherwise whirling will gradually die out, owing to bearing resistance, air resistance, etc. The speed of rotation of the shaft may be greater than, equal to or less than its natural whirling speed.

For the case where the shaft is deflected under gravity, its plane of deflection is stationary. When the shaft rotates in a clockwise direction, the disturbing torque due to internal friction acts in a clockwise direction, Fig. 3. When the shaft rotates counter-clockwise, the disturbing couple must urge the shaft in a counter-clockwise direction. For the case where the shaft is deflected by centrifugal force, its plane of deflection will rotate at its characteristic angular velocity. In this case the disturbing torque depends upon the speed of rotation of the shaft referred to this revolving plane of deflection. If the shaft rotates at a speed higher than the velocity of revolution of the plane of deflection to which it is referred, the disturbing torque will urge the shaft forwards in its path of whirl, and whirling may be built up. If the shaft rotates at a lower speed than the speed of the revolving plane to which it is referred, the disturbing torque will urge the shaft backwards against its path of whirl, and whirling will be damped out. In mathematical terms, if the characteristic angular velocity of the revolving plane of deflection is ω_w and if ω is the angular velocity of rotation of the shaft, when ω is higher than ω , the internal friction disturbing torque tends to urge the shaft forwards and whirling may build up, and if ω is lower than ω , this disturbing torque tends to urge the shaft backwards and whirling will be damped out. When $\omega=\omega$, the disturbing torque is zero for the case of whirling under centrifugal deflection just as it is zero for the case of the stationary gravity deflection when $\omega=0$. We have, therefore, reached the important conclusion that, in order to build up a whirling from internal friction in the shaft at the resonant speed ω_w, the rotation speed of the shaft must be greater than ω^w, and if the rotation speed is less than ω_w, the disturbing couple will be negative, and will tend to damp out such a whirling.

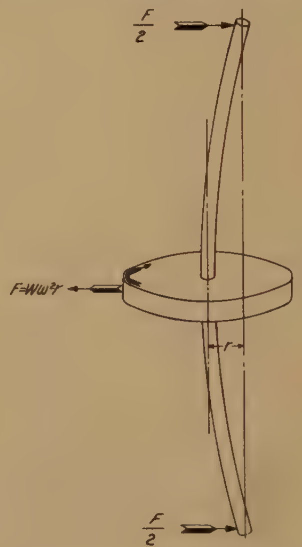


Fig. 5. Deflection Due to Centrifugal Force

Assuming that the disturbing force is proportional to the velocity of rotation of the shaft, we have for the case of deflection under gravity—

$$F=K\omega \tag{1}$$

where F = disturbing force
ω = rotational speed of shaft
K = a constant

For the case of deflection due to centrifugal force during whirling, we have—

$$F=K(\omega-\omega_w) \tag{2}$$

where ω_w = whirling speed (see Fig. 5)
K = a constant

Two Kinds of Internal Friction

Considering the whirling shaft, we will study in this article two different cases where a disturbing couple due to internal friction is present.

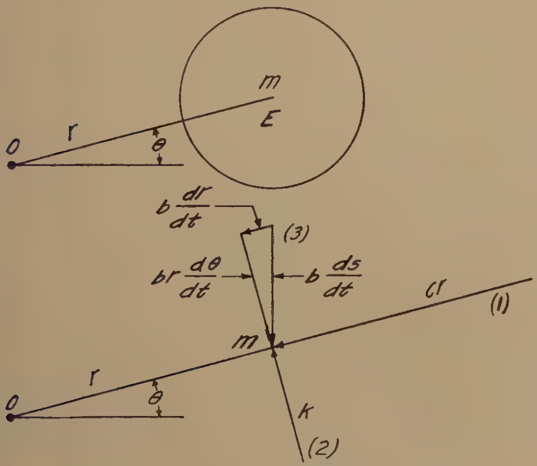


Fig. 6. Forces which Act on the Center of Mass m of the Shaft During Whirling

The first is that represented by equation (2) where the internal friction is similar in its action to an ordinary viscous friction, where the stresses required to overcome it are proportional to the velocity of extension and compression of the fibers. Velocity of extension and compression of fibers depends upon the velocity of rotation and amount of deflection. Therefore equation (2) becomes—

$$F=ar\ (\omega-\omega\ ) \tag{3}$$

where r = amount of deflection (Fig. 5)
a = proportionality factor

The second case is where the frictional forces arise from a squirming or working motion of the shaft in tight fits produced by the shrinking on of bushings or of wheels, or of impellers. These forces, although external to the metal of the shaft, are internal to the structure as a whole. In this case, we are dealing with sliding frictional forces. Sliding frictional resistance is ordinarily not dependent upon velocity of sliding motion. It is approximately a constant except when the slipping is being started, during which stage the resisting force is somewhat greater. If this friction is assumed constant, the disturbing force represented by equation (3) becomes independent of r and ω, and we have—

$$F=a \tag{4}$$

where the constant a in this equation has in general a different value from that in equation (3).

In all rotors made up of external parts shrunk on to a shaft both types of friction are likely to be present in greater or less degree.*

Derivations of Equations of Whirling Motion

Assume an ideal case of a perfectly balanced shaft, or one whose geometrical center and center of mass coincide at all points.

Fig. 6 shows a cross section of the displaced shaft where m is the equivalent center of mass and E the geometrical center, which in the assumed case of perfect balance must coincide; r represents the elastic displacement from the center line of the bearings O corresponding to the origin of a polar co-ordinate system about which m is whirling in a counter clockwise direction. At the moment considered m is moving in a direction opposite to $b\frac{ds}{dt}$.

We will derive the equations of motion of this mass m, one for radial acceleration a_r and one for tangential acceleration a_t. The resultant acceleration of m is produced by three forces shown in Fig. 6, (1), (2), (3).

cr is the elastic restoring force, proportional to r and always in line with r.

k is the disturbing force due to the internal friction which has already been discussed. This is always normal to r.

$b\frac{ds}{dt}$ is a mechanical resistance to m and acts always directly against its direction of motion. In other words it represents a damping to the whipping motion and tends to balance the effect of the disturbing force k.

From Fig. 6—

$$m\,a_r=-cr-b\frac{dr}{dt} \tag{5}$$

The signs are negative because both tend to resist an increase of r.

$$m\,a_t=k-br\frac{d\theta}{dt} \tag{6}$$

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* Since writing this article it has been found from preliminary experiments that internal friction in a carbon steel shaft is substantially a constant quantity and is independent of the speed of rotation for a given deflection of the shaft.

The first force is positive because it tends to produce an increase of θ, but the second tends to resist an increase of θ and is negative.

We know from mechanics that—

$$\left.\begin{aligned} a_r &= \frac{d^2r}{dt^2} - r\left(\frac{d\theta}{dt}\right)^2 \\ a_t &= r\frac{d^2\theta}{dt^2} + 2\frac{dr}{dt}\frac{d\theta}{dt} \end{aligned}\right\} \quad (7)$$

We will first take the case where $k = ar\,(\omega - \omega_w)$. ω is the rotational speed of the shaft which we will assume constant. From Fig. 6 the whirling speed $\omega_w = \frac{d\theta}{dt}$. This is not necessarily exactly a constant.

Combining (3), (5), (6) and (7) and remembering that $\omega_w = \frac{d\theta}{dt}$ we obtain the general differential equations of the radial and tangential motion components:

$$\left.\begin{aligned} m\frac{d^2r}{dt^2} - m\,r\left(\frac{d\theta}{dt}\right)^2 + b\frac{dr}{dt} + cr &= 0 \\ mr\frac{d^2\theta}{dt^2} + 2m\frac{dr}{dt}\frac{d\theta}{dt} + (b+a)\,r\frac{d\theta}{dt} - ar\omega &= 0 \end{aligned}\right\} \quad (8)$$

A particular solution for these equations may be obtained by assuming $\frac{d\theta}{dt} = \text{constant} = \omega_w$. On this assumption we find—

$$\left.\begin{aligned} r &= r_o\epsilon\,\frac{a\omega - a\omega_w - b\omega}{2m\omega_w}\,t \\ r &= r_o\epsilon\,\frac{(m\omega_w^2 - c)\,2\omega_w}{a\omega - a\omega_w + b\omega_w}\,t \end{aligned}\right\} \quad (9)$$

Where $r = r_o$ when $t = 0$

One relation was obtained from each of equations (8).

These equations give a means of determining ω_w because the equations (8) are simultaneous, and must have a common solution. This means that the coefficients of t in equations (9) are equal to each other, or

$$\frac{a\omega - a\omega_w - b\omega_w}{2m\omega_w} = \frac{(m\omega_w{}^2 - c)\,2\omega_w}{a\omega - a\omega_w + b\omega_w}$$

or

$$\left.\omega_w^4 + \left(\frac{b^2 - a^2 - 4mc}{4m^2}\right)\omega_w^2 + \left(\frac{a^2\omega}{2\,m^2}\right)\omega_w - \frac{a^2\omega^2}{4\,m^2} = 0 \right\} \quad (10)$$

If we choose ω_w so that it satisfies this equation, (9) must be a solution of equations (8).

This solution represents a spiral, not far divergent from a logarithmic spiral because θ is almost proportional to time.

We thus see that m takes a spiral path, just as the physical conditions would lead one to believe, that is to say, the shaft whirls outwards in a spiral path, Fig. 7. (In this case the rotation is clockwise.) If the exponents of equations (9) are negative, the spiral is decreasing and thus the disturbing force is negative and whirling dies out.

It seems probable that ω_w will not diverge far from the resonant frequency for which $\omega_w = \sqrt{\frac{c}{m}}$. It is the root of equation (10) in the neighborhood of $\sqrt{\frac{c}{m}}$ we are interested in and the others may be discarded.

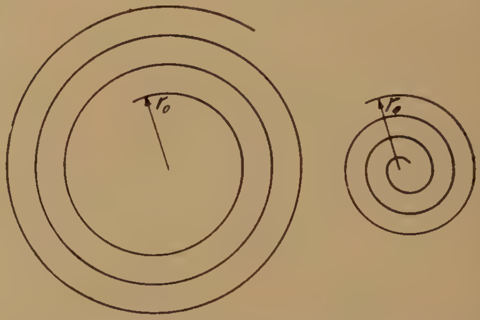

Fig. 7. Spiral Path of Shaft Centre for Increasing and Decreasing Whirl

We see at once from (10) that with no tangential forces acting, or when $a = b = 0$,

$$\omega_w = \sqrt{\frac{c}{m}} \quad (11)$$

which is the familiar expression for a resonant frequency.

Also if $b = 0$, ω_w is slightly greater than $\sqrt{\frac{c}{m}}$ and if $a = 0$, ω_w is less than $\sqrt{\frac{c}{m}}$ just as we should expect, because in general a resonant oscillation which is being built up has its frequency slightly raised, and a damped oscillation has its frequency slightly lowered.

When $a = 0$, $\omega_w = \frac{1}{2m}\sqrt{4\,cm - b^2}$ (12)

which has a familiar analogue in the case of a damped electrical oscillation.

We will now consider the case where $k = \text{const.} = a$. Combining (4), (5), (6) and (7) we obtain equations corresponding to equations (8), but where the disturbing force is a constant:

$$\left.\begin{aligned} m\frac{d^2r}{dt^2}-m\,r\left(\frac{d\theta}{dt}\right)^2+b\frac{dr}{dt}+c\,r&=0\\ m\,r\frac{d^2\theta}{dt^2}+2\,m\frac{dr}{dt}\frac{d\theta}{dt}+b\,r\frac{d\theta}{dt}-a&=0\end{aligned}\right\}\qquad(13)$$

Assume a "steady state" to be reached, as before, and let $\frac{d\theta}{dt}=\omega_w=a$ constant.

It can easily be shown that these equations are not satisfied by this condition unless—

$$\left.\begin{aligned} b\,r\,\omega_w-a&=0\\ r&=\frac{a}{b\omega_w}\end{aligned}\right\}\qquad(14)$$

In this case also $\omega_w=\sqrt{\frac{c}{m}}$

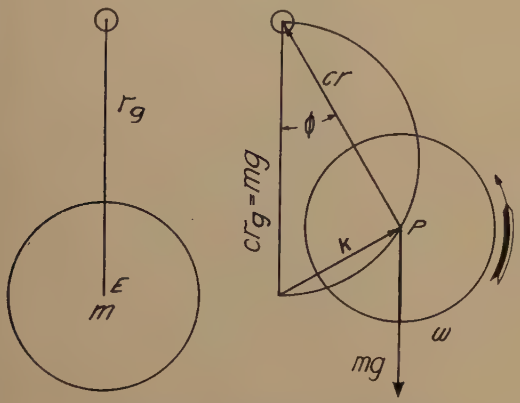

Fig. 8. Forces Acting on Shaft when Deflected Downward Due to Gravity and Displaced Sideways Through an Angle φ as Result of Internal Friction

The whirling builds up in a spiral motion whose exact equation we cannot readily obtain, but which approaches a circular motion in a path of radius given by equation (14).

In the former case, however, the spiral itself was the final state of motion, and must increase or decrease indefinitely as long as the forces on the mass m obey the laws assumed.

Transient Effects

The solutions given of equations (8) and (13) cover only the final states of motion in the two cases. The complete solutions must include terms representing a possible transient condition. Experiment shows that the transient condition is only of short duration on account of the amount of damping action necessarily present in actual cases. For the well-known case of whirling due to unbalance, it is not difficult to obtain the complete path of motion including the transient part[1]. The problem is then more easily handled in rectangular co-ordinates.

Effect of Gravitation on Whirling

Since most shafts operate in a horizontal position, we have also to take account of the effect of the deflection due to gravitation before we can be sure of our conclusions. We will first consider a rotating shaft whose cross section is shown in Fig. 8, acted upon by gravitation.

Gravitation causes the shaft to deflect a small amount r_g.

$$k=mg\sin\phi \qquad (15)$$

$$cr=mg\cos\phi \qquad (16)$$

$$\tan\phi=\frac{k}{cr}$$

where k = tangential disturbing force on m due to internal friction.

c = elastic constant of shaft = force per unit displacement

ω = rotation speed of shaft

ϕ = angle of deflection of plane of shaft deflection from vertical.

If $k=ar\omega$ as it does in the first case studied where internal friction force depends upon deflection and velocity of rotation,

$$\tan\phi=\frac{a\omega}{c} \qquad (17)$$

ϕ increases with ω, but can never be quite equal to 90 deg. no matter how great ω or a is.

If $k=a$ as in the second case studied where the internal friction force is independent of deflection and speed rotation,

$$\tan\phi=\frac{a}{cr} \qquad (18)$$

In this case ϕ must decrease as r, the deflection, increases and ϕ is independent of ω.

Equation (16) shows that the center of the shaft m swings out and up along a semicircular path with increase of ϕ for either case.

The effect of this deflection upon whirling is not difficult to picture. Referring again to Fig. 8, we see that the disturbing force k acts on m in a direction always perpendicular to r, its law of action not being affected by gravitation. The elastic restoring force upon m, however, acts towards a new center P displaced from O by the amount cr in Fig. 8

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(1) Foppl: "*Vorlesungen uber Technische Mechanik*" vol. IV page 281.

H. H. Jeffcott: "Lateral Vibrations of Loaded Shafts in the Neighborhood of a Whirling Speed," *Phil. Mag.*, Mar. 1919, p. 304.

for a given speed of rotation. In other words, P becomes a new position of equilibrium to which the center of mass m of the shaft tends to return when displaced. Its position is determined by the combination of the downward gravitational deflection and the resulting transverse deflection due to the disturbing force k. The position of P thus depends also upon the rotational speed of the shaft. Thus the effect of gravity is to displace the center of equilibrium with regard to the center O about which the disturbing force producing whirling acts. This reasoning, of course, holds only when Hooke's law, by which the elastic reaction is proportional to the deflection, is followed during the elastic displacement of the shaft.

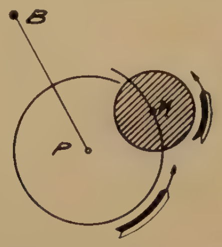

Fig. 9. Small Oscillations About the Elastic Center P which is Displaced Downwards and to the Right by Gravitation and Internal Friction

Suppose the shaft to be given an initial small oscillation about P, Fig. 9, which is the elastic center of vibration displaced vertically downwards due to gravity, and sideways due to rotational speed. The arrows show the direction of motion of the shaft, as it whirls about P, and its direction of rotation. The theory given, it will be recalled, requires that the rotation of the shaft and its whirling be in the same direction, and that the rotational speed must exceed the whirling speed.

We shall assume the oscillation to be circular. Fig. 10 shows the case of Fig. 9, with the path of motion of the center of the shaft cross section given. A, B, C and D are successive positions of the shaft center. P is the position of equilibrium as before. The disturbing force, due to internal friction, for the four positions of the shaft center as shown, is given in direction and magnitude by the arrows marked F.

This direction, it will be remembered, is always normal to the direction of displacement of the shaft center from the center line of the bearings O, or in other words, F is normal in each case to OA, OB, OC, and OD, but always acts towards the right of the figure for the case we have taken. The component of this force parallel to OP is seen to act always in the same direction as the corresponding component of motion of the shaft in its path of whirl. Therefore, there is a positive supply of energy due to this component of vibration. The components of force transverse to OP are seen to act alternately with and against the motion components. It is to be observed, however, that the positive work is the greater, because when the force and the motion are contrary as they are at A and D, the force F is acting at a greater angle to OP than at the corresponding points B and C where the work is positive. If the magnitude of F were greater at A and D than at B and C it is conceivable that the negative work done would be as great as the positive work and the transverse component could not build up. This would require that internal friction decrease with increase of bending of the shaft, however, which is most unlikely.

It is also to be noted that the impulses due to the vertical and transverse disturbing components act in time quadrature. We may, therefore, conclude for the cases we have studied that, when a small oscillation has once started, both components of vibration may be built up, giving a whirling motion of the shaft, approximating some form of an ellipse. The exact path of this whirl cannot be readily determined by analysis, but as its amplitude builds up to a value which is large compared with the gravity deflection, the disturbing effect of

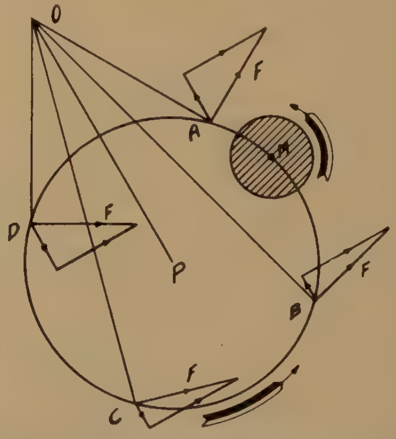

Fig. 10. Same as Fig. 9, but showing Circular Oscillation and the Components of the Disturbing Force F Parallel and Perpendicular to OP

gravity becomes negligible, and we are dealing with cases similar to those previously analyzed where there was no displacement of the elastic center.

Experimental Test of Theory

An experimental test was made with the apparatus shown in Fig. 11. The shaft contains a steel core which gives it its elasticity. The surface of the core is covered with a layer of small copper wires placed longitudinally and imbedded in a viscous substance, and these are held in place by a winding of the same wire, covering the entire shaft. This gives the shaft an artificial capacity for internal friction which comes into action during bending. The shaft is loaded with a flywheel of such weight that the first critical speed or resonant frequency is low and can be counted by direct observation.

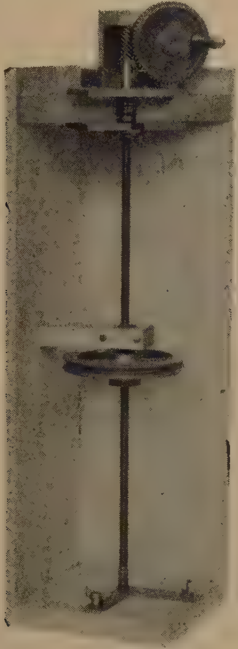

Fig. 11. Model Shaft and Flywheel to Reproduce Whirling

The shaft carrying the flywheel was found to whirl violently at the first critical speed. If the shaft is prevented from whirling by restraining it with the fingers it is possible to speed it up above this critical or resonant speed, when it again becomes stable. It may be driven up to a speed of several times that of the first critical speed by means of the hand-wheel and worm gear. If the shaft is struck with the fingers while revolving above the critical speed it whips or whirls violently *at the critical frequency* no matter what be its rotational speed so long as this is higher than the critical. This is exactly what the internal friction theory requires. It does the same whether in a vertical or horizontal position.

Summary

It is shown on theoretical grounds that an internal frictional action due to bending in a rotating shaft may cause the shaft to whirl or whip at any speed above the resonant or first critical speed.

This is true whether the friction is a friction in the shaft itself or a friction at its surface due to shrink fits, etc. It is also shown that the effect of a deflection due to gravitation should not interfere with the possible whirling. The theory is substantiated by experiments with a model shaft so built up as to have considerable internal friction.

ERRATUM

The last sentence of the third paragraph on page 169 of our March issue should have read: "Mr. Kimball's theory with some revision and extension will be published in the April number."

Studies in the Projection of Light

PART X

THE HIGH-INTENSITY ARC AND THE PARABOLIC MIRROR (Continued)

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

In this concluding section on the high-intensity arc there is but little treatment of the beam characteristic through the direct agency of geometry, but by the use of graphical methods the distribution of light is investigated in detail. The application of some of the simpler relations established in previous sections for the spherical and disk sources does, however, give information about several features and explains points that might otherwise remain obscure. The characteristic at short range is investigated and from the data so gained the investigation is extended to cover the increase of central intensity with distance, the inverse-square region, and the width of beam. The necessary test ranges for these different features is discussed in separate paragraphs, and in addition considerable first-hand test data are given on the photometric effect of moving the arc along the axis away from the focal point. The results here are of the highest engineering value as they point out the order of magnitude of mechanical accuracy that is necessary for the successful operation of a high-intensity searchlight. The general conditions for testing are different than in the previous case and the test limits are set by different features of the beam.—Editor.

Short-range Characteristics

The beam formation has been worked out for a 60-in. high-intensity searchlight at ranges of 610 ft., 1220 ft., and 2440 ft. The latter corresponds closely to the test distance used for outdoor testing on the searchlight range. The lower limit of 610 ft. is of course much too low for testing, but by noting the progressive changes between 610, 1220, 2440 ft., and the extreme range of Fig. 113* we may gain considerable information about the effects of short-range testing.

It should be remarked that the theoretical formulas derived for spherical and disk sources do not directly apply to the high-intensity arc, and while it is perhaps possible to extend those formulas to fit the case such an extension would hardly be profitable nor lead to a better understanding of facts than is gained from the drawings obtained by purely graphical means. Thus there is undoubtedly a region in the center of the beam that varies in illumination value as the inverse-square of the distance, but as an engineering factor we are more interested in the manner in which the intensity comes up to this inverse-square region. If the central beam intensity is 99 per cent of its full value at 5000 ft. and it is necessary to go to 10,000 ft. to gain the remaining one per cent, then the knowledge of the distance required to gain one per cent is of the highest engineering value. This is another phase of the theory of maxima and minima. As a theoretical problem, the exact condition for, say, the maximum efficiency of a motor is a thing sufficient unto itself, but as an engineering problem the regions on either side of this maximum point are of the greatest interest and importance. In considering almost any of the features of the high-intensity beam, we encounter a condition of gradual approach to some final state and nearly always there is some factor that makes us satisfied to accept something less than perfection.

The zonal images of Fig. 119 for the beam characteristic at 610 ft. are rounded off and there is only the slightest suggestion of the reverse curvature that is so noticeable in the original curves of crater brilliance. As the range increases these peculiarities of the curves reappear and finally at great distances (Fig. 113*) each zonal image has all the reversals of curvature of the original brilliancy curves.

It has been found in making tests at a radius of 16,000 ft. that the beam characteristics showed an indentation close to either side of the axis, and that the same beam tested at 2300 ft. seldom revealed this peculiarity. The actual test curves are shown in Fig. 124 and while these curves are greatly modified by atmospheric influences and mirror defects they form an interesting confirmation (or perhaps prediction would be more accurate) of the progressive change shown in the computed characteristics of Fig. 123.

There is one feature about the short-range characteristic that should not be overlooked. Guided by a blind faith in the universality of the inverse-square law, an engineer once attempted to measure beam intensity at a few feet distance from the mirror. The results, of course, did not agree with the simple theory. A little thought would have pointed out that the distribution immediately in front of the mirror is essentially the same as the distribution about the bare arc, and as the range increases the bare arc distribution, covering an arc of 120 deg. about the source, merges gradually into the distribution of the beam with its width of only two degrees. A beam analysis at an extremely short range is useless for gaining information about beam intensities, and the test range must be such that the beam will be in approximately final form, and any computed corrections must not exceed a few per cent unless we are absolutely certain of the accuracy of the various parts of the searchlight.

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*General Electric Review, March, 1924, p. 206.

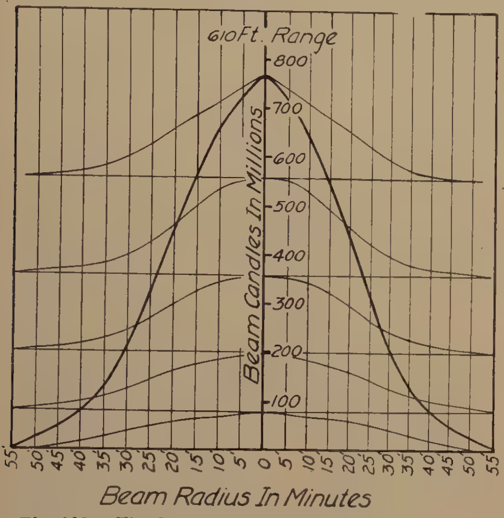

Fig. 119. The five zonal images are from the 10-deg. zones between 10 deg. and 60 deg. on the mirror. The resemblance between these curves and the crater brilliancy curves from which they are derived is nearly lost, due to the "out of focus" condition of the beam at 610 ft. range.

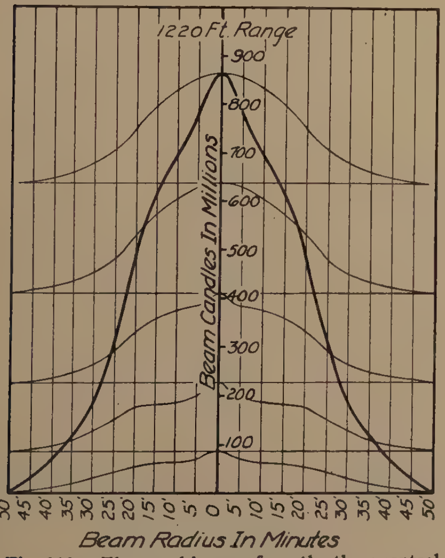

Fig. 120. The zonal images from the three central zones show some of the characteristic curves of the corresponding crater brilliancy curves, and the increase in range from 610 ft. to 1220 ft. has resulted in an increase of 100,000,000 candles in the apparent central intensity

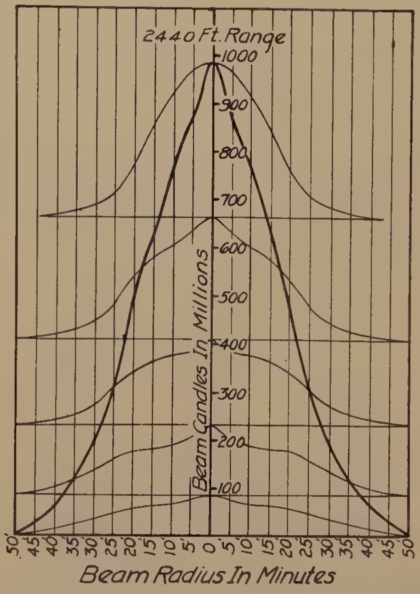

Fig. 121. At 2440 ft. range all the mirror zones except the outer one are in focus, and the beam is within 10 per cent of its theoretical maximum intensity, and the general distribution of light in the beam is nearly normal.

Increase of Central Intensity with Distance

The peak values of the curves of Figs. 113*; 119, 120, and 121 furnish us with the data for plotting the curve of increase of the central beam intensity with increasing range. The data apply to an optically perfect mirror, but as such a mirror is hardly to be found in searchlight practice it will be well to consider also the same phenomena of increase as found (by computation) for an imperfect mirror whose imperfections were measured and taken into account in the determination.

The theoretical beam comes up to the limit very slowly as illustrated in Fig. 122, and a glimpse into the underlying reasons may not be out of place. Let us consider ourselves standing in the center of the beam 2000 ft. from the searchlight and looking into the mirror. The entire mirror will seem to be a mass of moving flames that churn about without fixed direction or order. What we are viewing is the crater gas, and the confusion of movement is due to the fact that in each part of the mirror the same gas is seen from a different angle. If we watch the gas and crater closely it will become apparent that in the center of the mirror we see the center of the crater, but in the edges of the mirror we see a point back of the exact center of the crater, and if we have an instrument for measuring brilliancy this part of the mirror will be found to be less brilliant. The beam is therefore of less than full brilliancy for this is attained when the entire mirror is luminous with the brilliancy of the brightest part of the crater.

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*General Electric Review, March, 1924, p. 206.

At increasing distances, the edges of the mirror will be filled with light from points that approach the center of the crater and the beam intensity will therefore rise toward its final maximum.

The upper curve of Fig. 122 indicates that nearly 5000 ft. range is required to bring the central intensity up to maximum value. The diameter of the crater is 0.53 in. and it is instructive to compute how much of the crater is effective in determining this long range. Let us assume the actual crater to be replaced by a disk source of uniform brilliancy but unknown diameter. From equation (95) we have

$$L_o = \frac{2y^2}{r \sin 2\,a} \text{ in.}$$

where all dimensions are in inches. Taking $L_o = 60{,}000$ in., $a = 60$ deg. and $y = 30$ in., we get

$$r = 0.035 \text{ in.}$$

for the radius of the equivalent disk, and if we consider the light source to be spherical then equation (48) gives a value of

$$r = 0.017 \text{ in.}$$

These values show that only a small central part of the crater some 0.035 in. to 0.070 in. in diameter is the determining factor for the central intensity; and of course we might have arrived at the same results by noting the extremely narrow zone across the top of the crater brilliancy curves that might be considered uniform in intensity.

The lower curve in Fig. 122 is a computed curve taking into account the imperfections of a particular series of mirrors that have been rather fully investigated. This mirror scatters the light through a small angle and the sharp peak of the theoretical curve is lost. As a secondary result, the beam comes up to its full (but reduced) maximum rather quickly, and here the equivalent disk and sphere have diameters of 0.09 in. and 0.045 in. respectively.

A disk of uniform brilliancy and 0.53 in. in diameter would give full beam intensity at 640 ft. which is one-eighth of the distance for the ideal 60-in. high-intensity beam, and the test work is thus greatly simplified by relatively small defects in the searchlight; and again we have the rule that the difficulty of test increases as the precision of the thing being tested.

The Inverse-square Region

In the case of the spherical and disk sources the curve of beam intensity had a flat crest which we have called the inverse-square region. The high-intensity beam curve is rounded on top and we therefore have no visual evidence of the existence of the inverse-square region. We might infer, by analogy, that the exact center reaches a fixed maximum ahead of the other parts of the beam and that the width of the inverse-square region is about equal to the mirror diameter at double this distance, about twice the mirror diameter at three times this distance, etc.

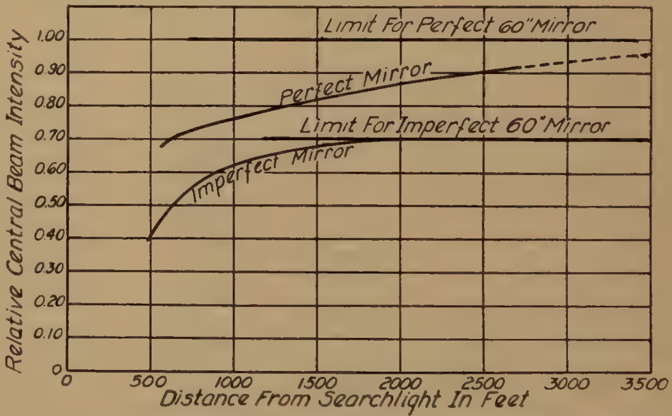

Fig. 122. The test range for a given arc and a given diameter of mirror increases rapidly with the degree of perfection of the mirror. The 60-in. mirror used in some of the outdoor tests gave its best intensity at less than 2000 ft., but this best value was only 70 per cent of the theoretical maximum. An optically perfect mirror would require at least 5000 ft. to give full central beam intensity

The curves of Fig. 123 give some clue to the manner in which the sides of the beam come into final form. There is a point at 0 deg. 20 min. from the axis where the 2440 ft. curve and the infinite curve cross, and at 0 deg. 12 min. and 0 deg. 5 min. they cross again so that at three points at least we have reached practically final and constant intensity. It would seem from this that for all practical purposes the inverse-square region of constant intensity is attained at less range than is full central intensity and we may therefore feel satisfied with any test condition that gives a good approximation of the full central maximum. This is in sharp contrast with the beam from the disk source which reaches full central intensity at ranges much short of those that give the proper width of crest.

Testing Distance for Central Intensity

The shortest distance at which the approximate maximum central intensity is reached is the best testing distance, and this distance in the actual case is greatly modified by the degree of perfection of the mirror. There is considerable experimental evidence that the 36-in. high-intensity searchlight takes nearly full theoretical range (about 2000 ft.) for a proper beam determination, but that the 60-in. searchlight may be tested at far less than its theoretical range of 5000 or 6000 ft. The reason for this is that the imperfections of the mirror have much less influence on the 36-in. beam than on the narrower beam from the 60-in. mirror. Taking these known (and measured) imperfections into account, the rate of increase of the central intensity is computed to follow the "imperfect mirror" curve of Fig. 116*. The full or 100 per cent value of this curve is some 30 per cent lower than that for the perfect mirror, so that the imperfect mirror will not at any range exceed the perfect mirror in intensity. The two curves are drawn to show this relation to the attainable maximum in each case.

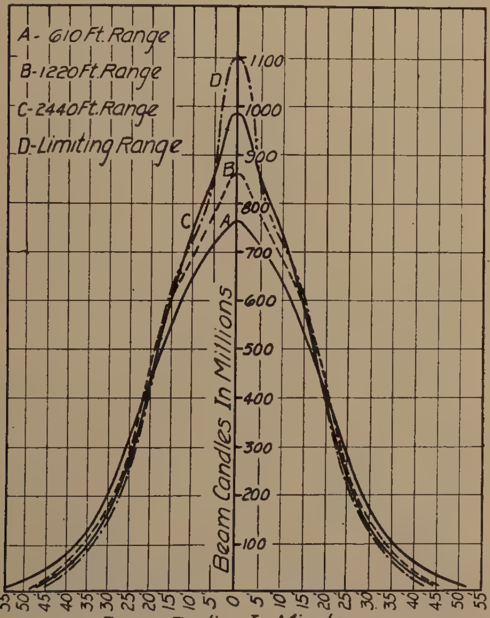

Fig. 123. The progressive change in beam formation as the range increases is illustrated by these characteristic curves computed for ranges of 610, 1220, 2440 ft. and at some range greater than 5000 ft.

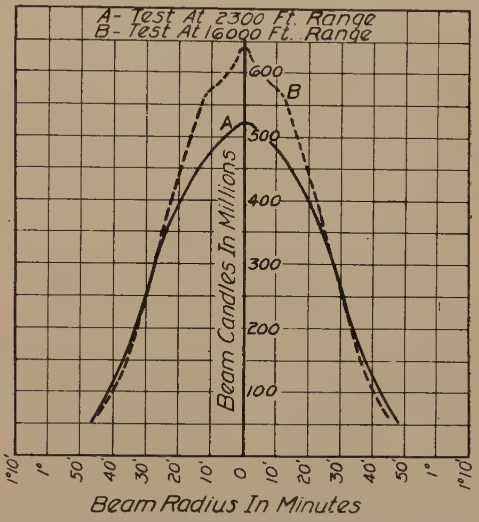

Fig. 124. The difference in form of the two characteristic curves taken at 2300 ft. and 16,000 ft. is too great to be adequately explained by the known geometrical changes that take place with increasing range; and, as will be shown later, the selective absorption of the atmosphere has much to do with this change

The two curves of Fig. 116* again illustrate the important fact that the imperfect searchlight requires less rigorous testing conditions than does the perfect one—a consideration of vast practical importance when considering small searchlights of intentionally low optical accuracy.

With accurate mirrors the testing distances for various standard sizes of mirrors may be computed to follow the rate of variation shown to hold for the disk source. In equation (98†) the test distance was found to vary as the focal length and inversely as the beam diameter. By adding a constant factor to this equation, we get for a high-intensity arc

$$L_o = \frac{3300 \tan a}{C_o\,(1 + \cos a)^2}\,F \qquad (119)$$

where a is the angle in degrees from the axis to the edge of the mirror, C_o is the observed beam width at great distances, and F and L_o are both expressed in either inches or feet.

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*General Electric Review, March, 1924, p. 206.

†General Electric Review, September, 1923, p. 629.

The curves in Fig. 115*, which were obtained graphically, indicate that at 2440 ft. the 60-in. beam attains 90 per cent of its full central value. The two test curves of Fig. 114* show the 2300 ft. test to give only 81 per cent of the value attained at 16,000 ft. This test was made with a defective mirror which should have shown the full intensity at short range, but the contradiction here is more apparent than real, for as will be discussed later the selective absorbing action of the atmosphere weakens the beam edges more than the center and when both beams are made to represent equal amounts of light in order better to compare their shapes, the central parts of the beam take on an entirely fictitious value. The opportunity for misreading the results of the 2300-ft. to 16,000-ft. comparison was somewhat lessened through the fact that a plain carbon beam displayed an almost identical change of shape, and it would be rather difficult to justify any geometrical explanation by such knowledge as we possess of the geometry of the disk source beam.

Width of Beam

It will be recalled that the validity of the "ten per cent" rule for the fixing of the beam width once the beam characteristic is determined by test was based wholly on experience, and in the case of the pure carbon arc in a 60-in. searchlight the agreement of the rule and the computation was reasonably complete. A doubt might be felt that the same rule would work out so well for the high-intensity crater with its extreme variation in brilliancy from center to edge and with the width added by the spilling of gas out of the sides of the crater. The matter is easily put to test for the beam formation has already been worked out graphically and the computation of beam width is readily made by equation (100†) using a crater diameter of 13.5 mm. and focal lengths of 650 and 375 mm. for the 60-in. and 36-in. mirrors respectively.

For the 60-in. searchlight we have
Computed width at 2300 ft. . . 1 deg. 11 min.
Graphical width at 2440 ft . . . 1 deg. 10 min.
Test width at 2300 ft. . . . . . . 1 deg. 40 min.
And for the 36-in. searchlight we get
Computed width at 2300 ft . . . 2 deg. 4 min.
Graphical width at 2440 ft . . . 2 deg. 4 min.
Test width at 2290 ft. . . . . 2 deg. 8 min.

A word of explanation is due here before we may discuss these results. The beam width is not the same in the vertical and horizontal planes. Tests on the 36-in. high-intensity arc with a protecting alcohol flame about the positive electrode have shown the vertical distance between 10 per cent points to be 2 deg. 31 min. (see Fig. 125) against 2 deg. 14 min. in the horizontal direction. The average width, 2 deg. 22 min., is therefore 1.066 times the horizontal width. Applying the same correction factor to the arc as now used without the alcohol flame, we get an average width of 2 deg. 8 min. from the measured horizontal width of 2 deg. 0 min. This correction for true average width must be made because the graphical data are based entirely upon averages in all planes around the axis of this crater.

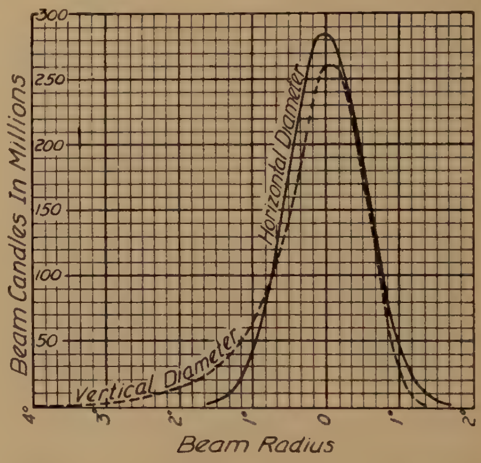

Fig. 125. The vertical diameter of the high-intensity beam is greater than the horizontal diameter. The central intensities should agree, but on account of the very limited number of readings taken the experimental errors were larger than usual. The test was on a 36-in. mirror at 2290 ft.

Referring back to the three widths given for the beams, we find that in both 36-in. and 60-in. beams the computed and graphical widths are in agreement but it should be noted that the exactness of the agreement is in part due to the particular distance at which the width was graphically determined. The test data in the case of the 60-in. beam are in serious disagreement with the computed and graphical values, but the 36-in. beam is in much better accord with the other values. It is now known that there were serious optical errors in the larger mirror, and the same errors to a lesser degree exist in the 36-in. mirror. The latter size is therefore

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*General Electric Review, March, 1924, p. 206.
†General Electric Review, September, 1923, p. 629.

better adapted for comparison with the theoretical data, and the former is more interesting as a problem in practical optics.

The beam width is of course a function of the distance from the searchlight, but the way in which the width varies with the distance is very different from the behavior of the spherical and disk source beams, and the equations and curves derived for those sources have no direct application to the high-intensity arc.

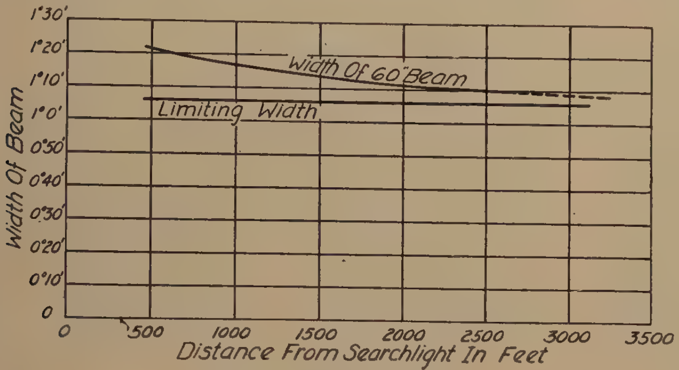

Fig. 126. The widths of the four beams of Fig. 123 when plotted against range give the upper curve which is asymtotic to a width of about 1 deg. 6 min. For practical purposes the curves may be considered to meet at 5000 ft.

In Fig. 126, the widths as determined graphically are plotted against distance for the particular case of the 60-in. mirror. The data of this curve may be used for the 36-in. mirror by multiplying the degree scale by $1.73\left(=\frac{650}{375}\right)$, and dividing the scale of distances by the same value, but this procedure cannot safely be extended to other searchlights that do not use the identical 150-amp. arc employed with the 36-in. and 60-in. mirrors because the distribution of luminous gas around the crater may be different.

In Fig. 124 are shown two characteristic curves of the same searchlight taken at a range of 2300 ft. for curve *A* and 16,000 ft. for curve *B*. There is a difference of about 0 deg. 6 min. which compares well with the difference of 0 deg. 4 min. indicated by the curve of Fig. 126 and the disagreement between the data is in the direction indicated by the selective action of the atmosphere.

Testing Distance for Width

The curve of Fig. 126 shows that with a highly perfect mirror the test range for determining the diameter of a 60-in. high-intensity beam should be nearly 5000 ft. But here again we must face the fact that the accuracy imposed upon the mirror is probably unreasonable in a commercial article. Any inaccuracy in the mirror or any lack of proper focusing will fortunately reduce the test distance for any desired degree of accuracy and therefore the 5000-ft. distance is an upper limit in the same way that the perfect beam of Fig. 113* represented a limiting condition. It would seem that a test range of 2300 ft., such as was used, was sufficient without being ideal. The curves of Fig. 114* offer some confirmation for this view, particularly as there are test data that indicate that the observed difference in width is explainable by atmospheric action rather than by the geometry of the beam.

A 36-in. mirror with the same arc will require only 36/60 of the theoretic range of the 60-in. mirror, but the reduction for mirror imperfection of the same order of magnitude will be much less. Thus the theoretical range of 3000 ft. cannot be reduced to 1500 ft. and it is probable that 2300 ft. falls short of the requirements although adequate for the larger searchlight. The reasons for this seeming contradiction will be treated more in detail when discussing errors of curvature in mirrors.

Movement of Source

Many striking changes take place in the high-intensity beam when the crater is moved in either direction along the axis so as to remove it from the focal point. A series of photometric tests were once run at a range of 2300 ft. to determine just what influence the focusing of the arc had on the central beam intensity, beam width, total flux, and on the visibility of targets. The last feature will be discussed later, but for the present the curves of Fig. 127 illustrate the answers found to the first three questions. The tests were made with a 36-in. mirror which in a previous paragraph was found to give data consistent with the theoretical results. Taking the focal length as the unit of measurement, we find that a movement of 0.01 focal lengths away from the mirror lowers the central intensity 25 per cent, and a movement of 0.01 focal lengths toward the mirror lowers it 22 per cent. A movement of 0.02 focal lengths results in losses of 58 per cent and 55 per cent for the plus and minus directions respectively. It is thus evident that the crater must be held within much closer limits than ±0.01

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*General Electric Review, March, 1924, p. 206.

focal lengths. When the crater is within 0.005 focal lengths (or 0.074 in.) the loss is 5 per cent and this may be taken as a reasonable requirement for maintaining full central intensity.

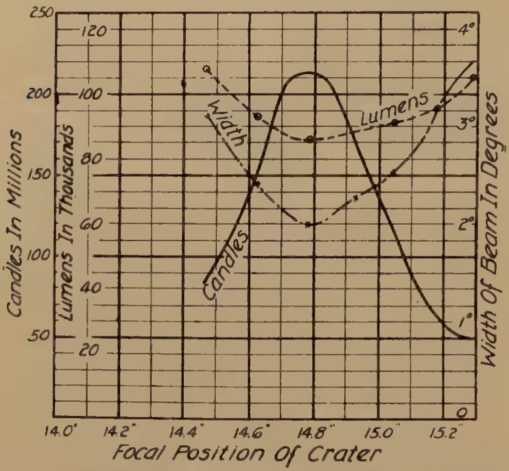

Fig. 127. The dependence of central beam intensity, beam width, and beam lumens upon the focal positions of the crater is illustrated by these curves for a 36-in. mirror

Once the central intensity begins to decrease, the 10 per cent points on the beam edge go out to lower intensities, and this spread added to the actual spread of the beam increases the width of the beam at a rapid rate, and the included beam flux also rises but at a lower rate. Thus a movement of 0.01 focal lengths toward the mirror increases the apparent beam width by 15 per cent and it is evident from this alone that considerable care is necessary for accurate operating and testing of the searchlight.

The beam characteristic curves at the various focal positions are shown in Fig. 128 in which the cycle of change greatly resembles the cycle gone through by the plain carbon searchlight as illustrated in Fig. 63.[*]

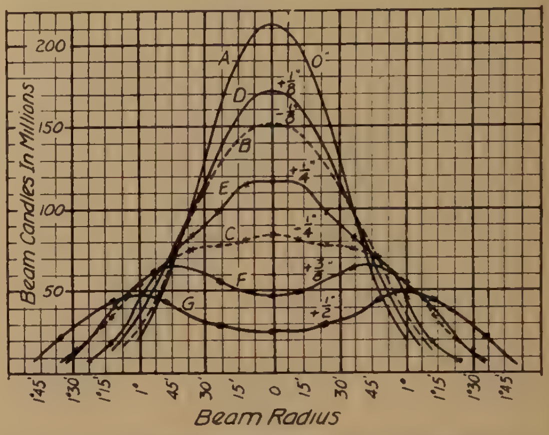

Fig. 128. The changes that take place in the distribution of light in the beam for positions of the arc closer to the mirror (—) and farther from the mirror (+) than the focal point are illustrated by these curves which apply to a 36-in. mirror

A: Crater at focal position
B: Crater ⅛ in. toward the mirror
C: Crater ¼ in. toward the mirror
D: Crater ⅛ in. away from the mirror
E: Crater ¼ in. away from the mirror
F: Crater ⅜ in away from the mirror
G: Crater ½ in. away from the mirror

A casual observer seeing the beam go through the changes illustrated in Fig. 128 would be greatly surprised if told the exact magnitude of the change he witnessed. The normal beam would seem to him to be of almost uniform intensity across a diameter

TABLE VII

COMPARISON OF TEST RANGES

60-deg. 60-in. Mirror

0.53 in. Diameter Source in Form of	Sphere	Disk	High-intensity
Beginning of inverse-square region			
Equation or Figure	Eq. 48[†]	Eq. 95	Fig. 122
Distance L_o	327 ft.	654 ft.	5000 ft.
1 per cent error in width			
Equation or Figure	Fig. 32[‡]	Fig. 60[§]	Fig. 126
Distance L_e	2130 ft.	1170 ft.	5000 ft.
Mid-radius Region			
Related to	8 L_o	4 L_o	....
Distance	2500 ft.	2500 ft.	2500 ft.

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[*] General Electric Review, November, 1923, p. 783.
[†] General Electric Review, April, 1923, p. 232.
[‡] General Electric Review, May, 1923, p. 283.
[§] General Electric Review, November, 1923, p. 781.

even if thrown on a flat surface where the illumination could be readily viewed. The center would of course seem somewhat brighter than the edges, but hardly in the ratio of ten to one. The tendency here is for the eye to minimize the differences in illumination. From this observation we might be tempted to reason that the beam *G* of Fig. 128 would give an illuminant of great apparent uniformity. Our casual observer, however, would not hesitate to pronounce the illumination a ring of light with a dark or black center. Here the eye exaggerates the differences of illumination. The writer must confess he has found no reasonable explanation for this phenomenon and it must therefore stand as an observed fact that has a bearing on searchlight practice in only one known way. A beam of light spread to cover a greater area should usually not be widened further once the dark center has appeared. In theory the beam might be doubled in diameter; in practice the increase is less than that and may amount to only 83 per cent as in Fig. 128.

Testing Distance for Entire Characteristic

It was found during the investigation of the spherical source with a 60-deg. mirror that the test distance for width should considerably exceed L_o, possibly by as much as six or eight times, and the correct measurement of the inverse-square region required a range slightly greater, say 8 L_o. Here L_o was the short range feature and the inverse-square region took the greatest distance.

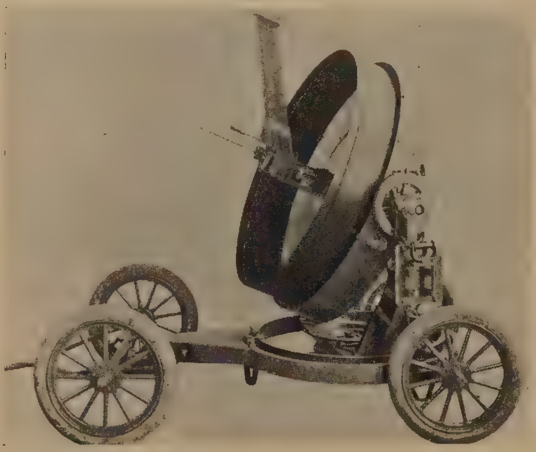

Fig. 129. This 60-in. open type searchlight is provided with a shallow barrel to give some protection from wind and a chimney to carry off the fumes from the arc

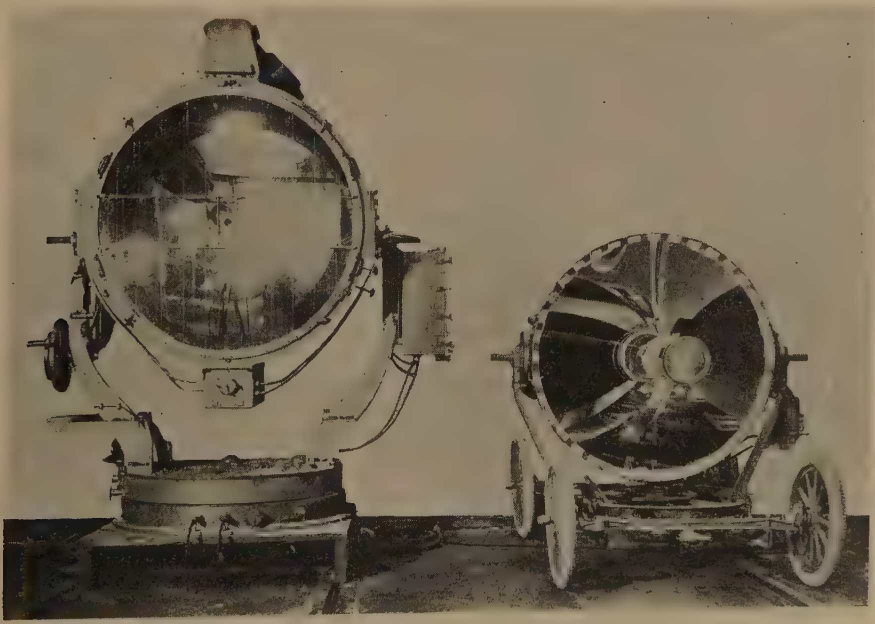

Fig. 130. The barrel-type 60-in. searchlight on the left is intended for permanent location and is designed for strength and rigidity. The open-type 60-in. on the right is of the lightest construction in order to make it easily portable over rough and uneven ground. The operating characteristics of the arc vary almost as much as do the mechanical details

The ideal disk source gives a slightly different relation between the three factors. A point in the beam at about half radius is the last to get into approximately final intensity (at about 4 L_o), but the measurement for width can be made at only twice L_o. It should be borne in mind that L_o in the case of the disk is twice the L_o for the sphere, and therefore 4 L_o in the latter case is equal to the 8 L_o of the former case, that is, for equal diameter of source the test distance for the entire beam is the same for sphere and disk. This, of course, applies only to a 60-deg. mirror for reasons noted in the explanation of the disk source and a mirror containing a 90-deg. zone.

The high-intensity arc gives a beam that comes first into shape at the mid-radius, and the central and edge points are about equal in range requirements. We may therefore select the test range from an examination of the data on width or central intensity with some assurance that all intermediate points will be satisfied. The actual ranges for three typical sources are worked out in Table VII. The center of the spherical source beam requires less range for its determination than does the disk source beam, but the edge of the spherical beam requires double the distance required by the disk. The two beams take the same distance for mid-radius points in the beam, and this distance being a maximum it is the determining factor for setting the test range. The high-intensity beam takes double the range of either of the other two, but this double distance is determined by features that were most easily satisfied for the sphere and disk.

The Graphical Treatment of Circuits Containing Iron Core Reactances and Capacity

By Lionel Fleischmann

Schenectady Representative, Allgemeine Elektricitäts Gesellschaft

Circuits possessing variable self induction and capacity are difficult to solve analytically. As an alternative, Dr. Fleischmann here presents a graphical method of treatment. Its remarkable simplicity is readily apparent and it should prove a very useful tool to engineers who are confronted with the problem.—Editor.

While the behavior of circuits containing self-induction of constant value and capacity is well known and the effect of resonance is daily made use of by millions, the characteristics of circuits with variable self-induction and capacity are not so widely known. This is due to the fact that such circuits do not easily lend themselves to analytical treatment. Even if a not very exact expression for the magnetization curve is used equating current and induction, this at least must be of the form $ax+bx^3$, where x is the induction and a and b are constants to be determined in such a manner as to make two points of the given magnetization curve coincide with the analytical expression. But even in this simplest case, the solution of the differential equation leads to elliptical integrals, which always involve some complications.

In setting forth the graphical treatment of these circuits, one shortcoming of the method used must be mentioned in the very beginning. We shall treat the circuits as if only sine voltages and sine currents are encountered. But it is well known that both can never go together in circuits containing iron worked beyond the bend of the saturation curve. It will therefore always be necessary to remember that the graphical method will yield numerical results which are only approximately correct. On the other hand, the qualitative results, otherwise not easily foreseen, check up very well with experimental investigations.

In Fig. 1, curve I is the magnetization curve of an iron core reactance giving the impressed volts E for a given frequency as a function of the current J. The straight line II shows the current taken by the capacity as a function of the voltage at a given frequency. If the self-induction and capacity (Fig. 2) are arranged in series, the same current will traverse both, but the voltages impressed upon either of them will be in phase opposition. Therefore, the total voltage of the circuit will be given by the difference of the ordinates belonging to the same current. If we plot these voltages (Fig. 3) in relation to the current we obtain a curve of a peculiar nature. The voltage first rises with an increase of current, then drops to zero, and finally rises anew with reversed sign in reference to the current. Or putting it the other way, starting with zero volts, there would be up to a certain voltage three different values of current belonging to the same voltage. Now, in such cases, we know that this is hardly ever realizable in nature and what really would happen is this: the current first increases slowly with the voltage and then suddenly jumps from *a* to *b* (Fig. 3).

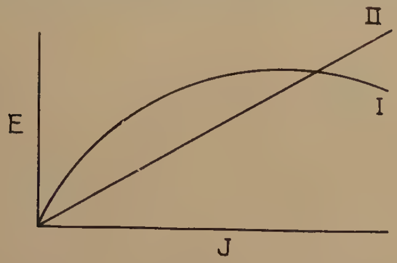

Fig. 1

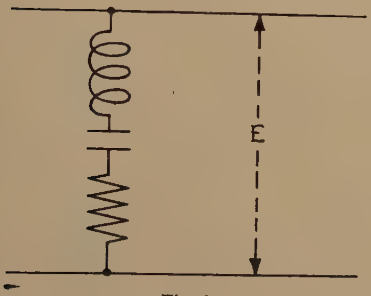

Fig. 2

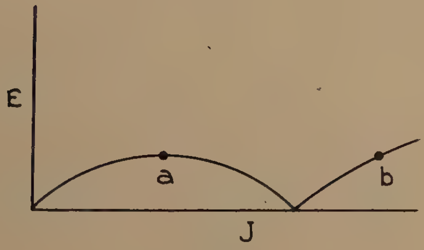

Fig. 3

So far we have omitted resistance which of course will always be present in actual tests. We therefore have to correct our graphical representation to take this into account, and then we can see whether the experimental results uphold the theory.

As we have pointed out in the beginning, we assume sine voltages and sine waves. This enables us to deal with the influence of resistance in a very simple manner. Drawing once more the straight line, Fig. 4, showing the dependence of voltage and current in a circuit containing capacity, any line parallel to the axis of the abscissa will be in phase with the voltage drop due to the resistance. The voltage drop is furthermore proportionate to the current. If we therefore draw a second line starting from the origin *o*, *bc* will be proportionate to *oa*, for triangle *oaf* is similar to triangle *bcf*.

The total voltage which we must impress on the circuit is given by *dc* in Fig. 5 wherein *bd* is the difference of voltages of condenser and reactance and *bc* is the resistance drop.

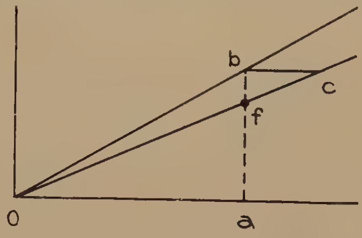

Fig. 4

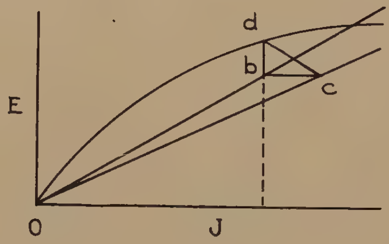

Fig. 5

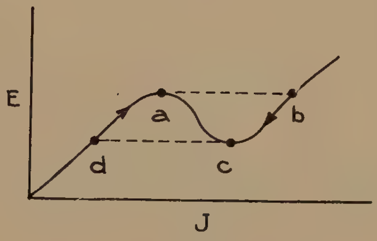

Fig. 6

The angle of the straight line determining the locus for the ohmic drop is best obtained by drawing for a given current the ohmic drop *bc* in the volt scale and connecting point *c* with *o*.

If we determine different values of voltages belonging to different currents, we obtain a voltage curve in function of the current as shown in Fig. 6. With rising voltage the current will first increase up to the point *a* and then with a slight increase of voltage will leap to the value *b*. On reducing the voltage from point *b* it will decline continuously to the point *c* and then suddenly reduce from *c* to *d*. At the same time, the phase changes from leading to lagging and vice versa. For other frequencies the diagram is easily altered. With increase of frequency for a given current, the reactance voltage rises proportionally while the voltage at the condenser terminals decreases. The ohmic drop for a given current remains the same.

If, instead of having the reactance and the capacity in series, we connect them in parallel (Fig. 7), a similar diagram may be used.

We are now interested in the current supplied to the circuit. We again plot the reactance voltage (Fig. 8) as a function of current J, ab will then be the current taken by the reactance, ac is the condenser current, and bc being the difference is the line current. Theoretically at point d the current ought to be zero and we can furthermore deduce that there is one voltage for every frequency at which the current will be zero. This is different from a circuit containing constant self-induction. Then, there is one frequency for which the two currents balance and it is independent of the voltage. As stated before, the current in the series connected circuit shows the tendency to leap. No such discontinuity takes place in the parallel connected circuit. Starting with zero volts, the current first increases then decreases rapidly, and finally increases again. Its behavior is shown in Fig. 9. Experiments show that it is really in accord with the facts.

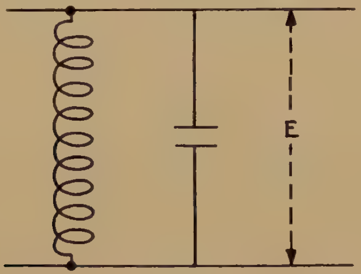

Fig. 7

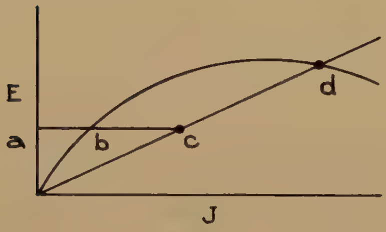

Fig. 8

The behavior of the iron core reactance is of importance in circuits making use of the so-called Petersen earth coil. This coil is intended to reduce the value of the earth return current in case of an arcing ground. Its theory is best understood in regard to the simple case of a single-phase circuit (Fig. 10). Let the supply voltage $2E$ be grounded through a reactance coil at its neutral point O. The capacity to earth of each of the transmission lines being K, as long as both lines are in there will be no current flowing through the reactance coil. But as soon as one line is grounded (Fig. 11) the reactance coil will be subjected to the impressed voltage E while the intact line behaves like a condenser upon which the voltage $2E$ is impressed. The current taken by it will be $2\pi_{\sim} EK$ and this must equal the current taken by the reactance earth coil. Instead of writing $2\pi_{\sim} EK$, for the charging current of the line, we put $E\,2\pi_{\sim} K$. This change makes it at once possible to apply the diagram given above.

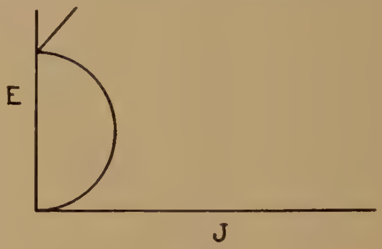

Fig. 9

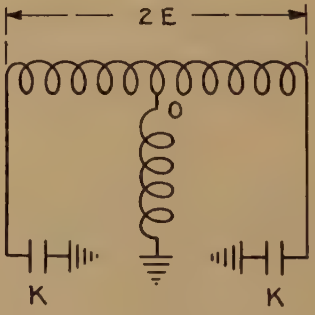

Fig. 10

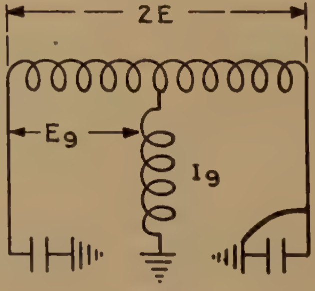

Fig. 11

All we have to do is to lay off the straight line, giving the condenser voltage as a function of the current so that $J = E\,2\pi_{\sim} K$. For the normal line voltage to ground, Eg, the current taken by the reactance ought to be equal to Ig, then the current returning through the earth will be zero.

Measuring the Reactive Component

By John Auchincloss

Switchboard Engineering Department, General Electric Company

Never before has the matter of power-factor been given the serious consideration it is receiving to-day. Higher power-factor, with unity as the desideratum, now appears in a great many instances as the only immediate solution to the operator's problem of meeting to-morrow's increased demand for power from his system that is already operating practically at full capacity under the prevailing power-factor. In applying our knowledge of the causes of poor power-factor, some suitable device is essential to furnish a direct reading of the effect of changes made and to assist in maintaining a high standard. The familiar power-factor indicator is such a device; the reactive volt-ampere indicator and meter are others but not as well known. Each has a field in which it is better suited than the other. The theory of operation of the reactive volt-ampere measuring devices is minutely explained in the following article.—Editor.

General

An indication of the value of the reactive component, or of the displacement angle from which it is derived, is of paramount importance in the proper adjustment of the field strength of most synchronous machines. Even where asynchronous machinery is employed, such an indication is of value in enabling the consumer to distribute his load in such a manner that the all-day power-factor of his plant, measured at his incoming line, may be as high as possible. Particularly is this desirable in those cases, which are becoming more and more frequent, where the terms of the power supply contract penalize the consumer for low power-factor.

As the value of the reactive component varies with the sine of the displacement angle, the indication may be either in terms of the displacement angle or in terms of the component. By itself the reactive component is rather difficult of direct measurement, but it may readily be measured indirectly as a factor in the product $ei \sin \alpha$, where α is the displacement angle between the voltage e and the current i. In this product the quantity $i \sin \alpha$ represents the reactive component of the current i. This component is in quadrature phase with the active or power component $i \cos \alpha$.

The device measuring the instantaneous value of $ei \sin \alpha$ is known as a "reactive volt-ampere indicator," while the device which measures the instantaneous value of α directly in terms of its cosine is called a "power-factor indicator."

Where the indications of a single-phase instrument are sufficiently accurate to meet the requirements of certain so-called balanced polyphase circuits (balanced as to currents and displacement angles) there is usually little choice between the reactive volt-ampere indicator and the power-factor indicator. The former, being nothing but a single-phase wattmeter with special calibration, allows of much simpler connections; but, operating on the wattmeter principle, it cannot be used with current and potential transformers the product of whose ratios differs from that for which the instrument was originally calibrated. For example, if it be desired to obtain indications on each of several circuits by means of one instrument and transfer switches, the reactive volt-ampere indicator will give true readings only when the watt capacity of all the circuits is the same*; whereas the power-factor indicator, measuring the angle only, will give correct readings irrespective of the watt capacity of the individual circuits.

On the other hand, the power-factor indicator indicates in percentage only, while the reactive volt-ampere indicator gives a more definite indication of the value of the reactive volt-amperes actually circulating through and heating the machine.

The single-phase characteristic of the power-factor indicator, however, renders it unsuitable for use on unbalanced circuits or for integrating purposes, the entire field in these directions being covered by polyphase reactive volt-ampere indicating and integrating meters.

The best that can be obtained with the power-factor indicator is a graphic record, the integration of which is a task of no mean magnitude, whereas the reactive volt-ampere principle lends itself readily to direct integration by means of the ordinary induction type watthour meter.

Single-phase

Though polyphase measurement, being relatively much more important, is chiefly intended as the subject of this article, yet for a ready understanding of the operating principle of the polyphase instrument a preliminary digression into the theory of the single-phase instrument may prove useful.

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* Assuming that, as the watt capacities are equal, the products of the current and potential transformer ratios will be the same for all circuits.

In Fig. 1 let the current i lag its voltage e by the angle α. Then if a single-phase wattmeter be connected in such a circuit the torque exerted upon its shaft will be proportional to $ei \cos \alpha$. The reactive component $i \sin \alpha$ produces no torque upon the shaft since it is in quadrature phase with the voltage e. If, however, it were possible to rotate e backward through 90 deg. to the position e' it is clear that the torque conditions would be completely reversed, that due to $e' i \cos \alpha$ being zero while the product $e' i \sin \alpha$ would exert a torque proportional to the reactive volt-amperes in the circuit. But since $e=e'$ in magnitude it follows that $ei \cos \alpha$, where e is the normal voltage, and $ei \sin\alpha$, where e is a quadrature voltage, represent respectively the power and the reactive volt-amperes in the circuit, so that when $\alpha=45$ deg. $ei \cos \alpha = ei \sin \alpha$, and all other values of power and reactive volt-amperes will vary respectively with the cosine and sine of the angle of displacement.

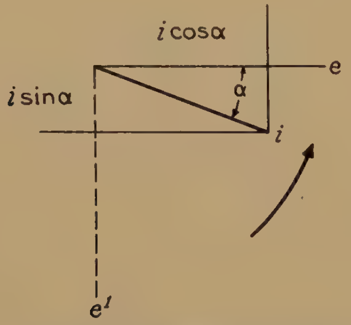

Fig. 1. Vector Diagram Illustrating Derivation of Torque in Reactive Volt-ampere meter by Means of Quadrature Potential

Now if the power in a single-phase circuit is $ei \cos \alpha$, in an n-phase circuit it will be $n\, ei \cos \alpha$ if the power in all the phases is the same. But if the power in all the phases is not the same, then the total power will be the sum of the powers in all the individual phases which is

$$e_1 i_1 \cos \alpha_1 + e_2 i_2 \cos \alpha_2 + \ldots\ldots e_n i_n \cos \alpha_n.$$

Similarly if the reactive volt-amperes in a single-phase circuit be $ei \sin \alpha$, in an n-phase circuit the total reactive volt-amperes will be $n\, ei \sin \alpha$ when the reactive volt-amperes in all the phases are the same. When they are not all the same the total will be

$$e_1 i_1 \sin \alpha_1 + e_2 i_2 \sin \alpha_2 + \ldots\ldots e_n i_n \sin \alpha_n.$$

But since, as will be shown later, all commercial methods of measuring reactive volt-amperes on polyphase circuits depend for their accuracy upon balanced voltage conditions, that is $e_1=e_2=\ldots e_n=e$, the foregoing total may be written in the form

$$\text{R.v.-a.} = e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + \ldots\ldots i_n \sin \alpha_n). \qquad (1)$$

which is the fundamental equation for reactive volt-amperes in any circuit having balanced voltages.

Now in Fig. 1, although the voltage e cannot very well be changed to the position e' yet it is possible, by inserting a suitable resistor-reactor box in the potential circuit of the wattmeter, to lag the current in the potential coil 90 deg. behind the voltage e, which, in effect, is the same as rotating e backward through 90 deg. As a matter of fact this method is occasionally employed when it is required to read reactive volt-amperes on a single-phase circuit, although on account of the relative unimportance of most single-phase circuits this requirement is extremely rare. It should be noted that with this connection the reactor may give rise to error due to variation in frequency.

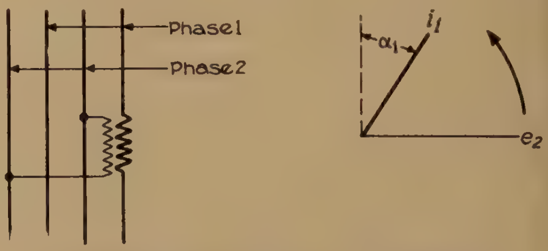

Fig. 2. Single-phase Reactive Volt-ampere Indicator on a 2-phase 4-wire Balanced Load

Two-phase

Fortunately, however, on the principal polyphase systems, two-phase and three-phase, it is generally possible to find a quadrature voltage across an opposite phase without having recourse to the use of the resistor-reactor box. For example, in Fig. 2, if we connect the current coil of a single-phase wattmeter in phase *1* of a two-phase circuit and the potential coil across phase *2*, the fields arising from the two coils will be in quadrature phase (dynamometer type instrument) and the shaft will experience a torque proportional to $e_2 i_1 \sin \alpha_1$.

But from a preceding paragraph we know that the true reactive volt-amperes in phase

1 should be $e_1 i_1 \sin \alpha_1$, so that for the instrument to read correctly the equation

$$e_1 i_1 \sin \alpha_1 = e_2 i_1 \sin \alpha_1$$

must be true, and it is only true when

$$e_1 = e_2.$$

In other words, the instrument will read the correct reactive volt-amperes in phase *1* only when the voltages of phase *1* and phase *2* are equal or balanced. This statement may be said to apply to all methods of measuring reactive volt-amperes in which the quadrature relationship is obtained by energizing the potential coil from a voltage other than the one driving the current through the current coil.

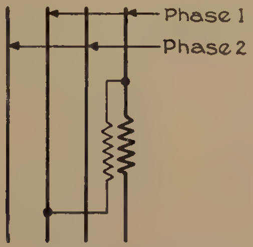

Fig. 3. Single-phase Wattmeter on a 2-phase 4-wire Balanced Load

If the two-phase circuit shown in Fig. 2 is balanced as to reactive volt-amperes, then the single-phase instrument equipped with a zero-center scale, which also multiplies by 2, will read the total reactive volt-amperes of the two-phase circuit whether the current be leading or lagging, the reading being $2ei \sin \alpha$.

Connected as a wattmeter as shown in Fig. 3, the same instrument will read $2ei \cos \alpha$, which is the true total power under balanced power conditions: that is when

$$e_1 i_1 \cos \alpha_1 = e_2 i_2 \cos \alpha_2.$$

It should be added, however, that these conditions are seldom encountered in actual practice, the example being cited merely to illustrate in its simplest form the method whereby the quadrature relationship is obtained on a polyphase system.

On a two-phase system in which the reactive volt-amperes per phase are not equal, as may readily be the case in the circuit of a two-phase generator supplying an unbalanced load, the true reactive volt-amperes is no longer the quantity $2ei \sin \alpha$, but becomes

$$e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2)$$

which quantity obviously cannot be measured by a single-phase instrument. It can, however, be measured by a polyphase instrument having one element connected to current i_1 and potential e_2, and the other element connected to current i_2 and potential e_1 as shown in Fig. 4. Both elements being rigidly fastened to a common shaft, the total torque developed will be proportional to

$$e_2 i_1 \sin \alpha_1 + e_1 i_2 \sin \alpha_2$$

which, since we have already stipulated that the voltages must be balanced, becomes

$$e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2)$$

and this quantity, from equation (1), is the true reactive volt-amperes in a two-phase circuit with balanced or unbalanced reactive volt-amperes per phase.

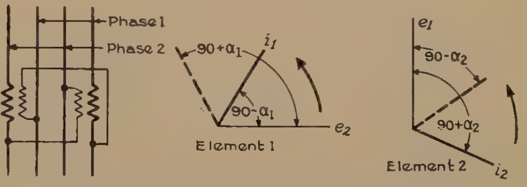

Fig. 4. Polyphase Reactive Volt-ampere Indicator or Meter on a 2-phase 4-wire Unbalanced Load

Considering Fig. 4, it will be observed that with the phase rotation indicated by the arrow the lagging current i_1 will produce upon the common shaft a positive torque proportional to

$$e[i_1 \cos (90 - \alpha_1)],$$

while the lagging current i_2 will produce a negative torque proportional to

$$e[i_2 \cos (90 + \alpha_2)],$$

so that the net result will be a torque proportional to

$$e[i_1 \cos (90 - \alpha_1) + i_2 \cos (90 + \alpha_2)],$$
$$= e(i_1 \sin \alpha_1 - i_2 \sin \alpha_2)$$

But since we have already seen that the true reactive volt-amperes is the quantity

$$e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2)$$

it is apparent that the sign in the meter equation must be changed from negative to positive. This is accomplished by reversing the connection to the potential coil energized from phase *1* thereby giving this element a torque proportional to $-e_1 i_2 \cos (90 + \alpha_2)$ and making the total torque proportional to

$$e_2 i_1 \cos (90 - \alpha_1) - e_1 i_2 \cos (90 + \alpha_2),$$

which when $e_1 = e_2 = e$ becomes

$$e(i_1 \sin \alpha_1 + {}_2 \sin \alpha_2)$$

and this, as we have already seen, is the true reactive volt-amperes. It should be noted, however, that the selection of the potential coil to be reversed depends entirely upon the phase rotation of the system, for were the rotation the reverse of that shown in the diagram the currents i_1 and i_2 would take the positions shown dotted, and their respective torques would be proportional to

$$e[i_1 \cos (90+\alpha_1)] \text{ and } e[i_2 \cos (90-\alpha_2)]$$

in which case the coil connected across phase *2* would be the one to be reversed. The phase rotation, however, being so frequently unknown usually leaves the connections for the potential coils to be determined in the field during installation.

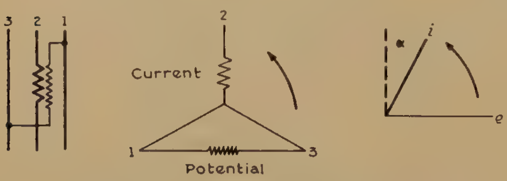

Fig. 5. Single-phase Reactive Volt-ampere Indicator on a 3-phase 3-wire Balanced Load

The indicating instrument is generally equipped with a zero-center scale, one side of which is marked "lead" and the other "lag." These markings must also be considered in connecting the potential coils otherwise the deflection will be in the wrong direction, indicating "lead" when it should indicate "lag" and vice versa.

Two requirements therefore enter into the problem of connecting a polyphase reactive volt-ampere indicator in a two-phase circuit: first, the torques of both elements must be in the same direction so that they are summated by the common shaft; and second, the summation so derived must be in the direction corresponding to the conditions existing in the circuit under observation.

In the integrating meter the speed and direction of rotation of the disks correspond to the magnitude and direction of deflection of the pointer on the indicating instrument so that these requirements apply equally to both types of devices. It might be noted also that the polyphase reactive volt-ampere indicator and the polyphase reactive volt-ampere-hour meter for use on two-phase circuits are nothing more nor less than standard indicating wattmeters and watthour meters, and with the correct watt connection will read accurately and directly in watts or watthours.

Three-phase, Three Wire

On a three-phase three-wire system the quadrature relationship for a single-phase instrument is obtained as shown in Fig. 5. The torque on the shaft is proportional to $\sqrt{3}ei \sin \alpha$, where e is the voltage per phase or to neutral,* so that if the voltages and reactive volt-amperes per phase are equal the scale may be made to read directly in total reactive volt-amperes by containing the multiplier $\sqrt{3}$. This gives $\sqrt{3}\sqrt{3}ei \sin \alpha = 3ei \sin \alpha$, which is the true reactive volt-amperes in a three-phase system when the reactive volt-amperes in all three phases are equal. Due to the $\sqrt{3}$ multiplier in the scale, however, this instrument without recalibration is obviously unsuitable for reading power on either a single-phase or a balanced three-phase system.

When the reactive volt-amperes in the system are not balanced or equal then the quantity $3ei \sin \alpha$ no longer represents the true total reactive volt-amperes, which, from equation (1) becomes

$$\text{R.v-a.} = e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$

Although this quantity cannot be measured by any single-phase device, yet, by employing a two-element instrument equipped with three current windings, the total reactive volt-amperes in such a circuit may be measured in a manner similar to that already described for measuring reactive volt-amperes on a two-phase system. In the three-current-coil instrument the middle coil, usually connected in phase *2*, is split into two equal parts which are arranged in such a manner that each half develops a torque proportional to $\sqrt{3}ei_2 \cos (30-\alpha_2)$ and $-\sqrt{3}ei_2 \cos (30+\alpha_2)$ respectively. The connections for the instrument are shown in

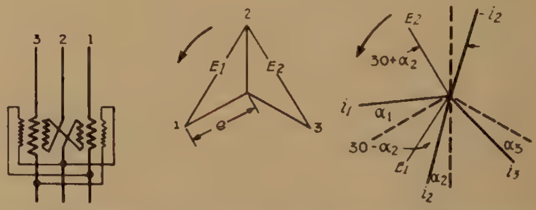

Fig. 6. Polyphase (3 Current Coil) Reactive Volt-ampere Indicator or Meter on a 3-phase 3-wire Unbalanced Load, or 3-phase 4-wire Load when Potential Transformers are not used. Not standard wattmeter

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* As distinguished from *E*, the voltage across the lines.

Fig. 6. Referring to this diagram, which shows the phase positions of the various currents and voltages, it will be observed that the torque is proportional to

$$E_2 i_1 \sin \alpha_1 + E_1 i_2 \cos (30-\alpha_2) - E_2 i_2 \cos (30+\alpha_2) + E_1 i_3 \sin \alpha_3$$

which, when $E_1 = E_2 = E = \sqrt{3}e$ becomes

$$\sqrt{3}e[i_1 \sin \alpha_1 + i_2 \cos (30-\alpha_2) - i_2 \cos (30+\alpha_2) + i_3 \sin \alpha_3)]$$
$$= \sqrt{3}e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$

but we have already seen from equation (1) that the true reactive volt-amperes on a three-phase circuit with balanced voltage is

$$e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$

wherefore the scale of the indicating instrument and the register of the integrating meter must both contain the divisor $\sqrt{3}$. With this reduction it is obvious that the meter will give correct indications for any condition of unbalance other than that of voltage. The introduction of the $\sqrt{3}$ factor in the scale, however, not only results in a special device (which from the viewpoint of both the manufacturer and the purchaser is undesirable) but precludes the possibility of its use as a wattmeter or watthour meter.

Another method frequently suggested, using a two-current coil instrument, is shown in Fig. 7. Apparently operating on the two-wattmeter principle the torque experienced by the shaft of this instrument is proportional to

$$E_2 i_1 \cos (90-\alpha_1) + E_1 i_3 \cos (90-\alpha_3)$$

which, when $E_1 = E_2 = E$ becomes

$$E(i_1 \sin \alpha_1 + i_3 \sin \alpha_3) \text{ or } \sqrt{3}e(i_1 \sin \alpha_1 + i_3 \sin \alpha_3).$$

With equal values of reactive current in phases *1* and *3* this torque is equivalent to $2\sqrt{3}\ ei \sin \alpha$, but we have already noted that under balanced conditions the true reactive volt-amperes should be $3\ ei \sin \alpha$. The reading must therefore be reduced in the scale and register by the ratio $\frac{3}{2\sqrt{3}}$, or by about 13.4 per cent. With this correction the reading with unbalanced reactive current will be

$$0.866E(i_1 \sin \alpha_1 + i_3 \sin \alpha_3).$$

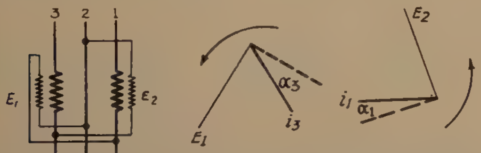

Fig. 7. Polyphase (2 Current Coil) Reactive Volt-ampere Indicator on a 3-phase 3-wire Load. Not correct when load is unbalanced

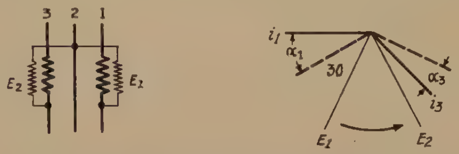

Fig. 8. Polyphase (2 Current Coil) Wattmeter on a 3-phase 3-wire Unbalanced Load

But from equation (1) we know that the true reactive volt-amperes when the reactive currents are not equal is the quantity

$$e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$
$$\text{or } \frac{E}{\sqrt{3}}(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$

so that if the instrument reads correctly the equation

$$0.866E(i_1 \sin \alpha_1 + i_3 \sin \alpha_3) = \frac{E}{\sqrt{3}}(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$

must be true.

By reduction this equation becomes

$$0.5 i_1 \sin \alpha_1 + 0.5 i_3 \sin \alpha_3 = i_2 \sin \alpha_2$$

But $i_2 \sin \alpha_2 = i_1 \cos (30-\alpha_1) - i_3 \cos (30+\alpha_3)$*

$$= 0.866 i_1 \cos \alpha_1 + 0.5 i_1 \sin \alpha_1 - 0.866 i_3 \cos \alpha_3 + 0.5 i_3 \sin \alpha_3$$

So that

$$0.5 i_1 \sin \alpha_1 + 0.5\, i_3 \sin \alpha_3 = 0.866 i_1 \cos \alpha_1 + 0.5 i_1 \sin \alpha_1 - 0.866 i_3 \cos \alpha_3 + 0.5 i_3 \sin \alpha_3$$

which, of course, is only true when $i_1 \cos \alpha_1 = i_3 \cos \alpha_3$. This result shows that in general the instrument, with this connection, is correct only when the loads per phase are equal.

To account for the inaccuracy of the instrument on unbalanced load let us consider its behavior when connected to measure watts, without the 13.4 per cent reduction in the scale. From Fig. 8 the torque is evidently proportional to

$$E_1 i_1 \cos (30+\alpha_1) + E_2 i_3 \cos (30-\alpha_3)$$

which, with balanced voltages, becomes

$$E[i_1 \cos (30+\alpha_1) + i_3 \cos (30-\alpha_3)]$$
$$= E(0.866 i_1 \cos \alpha_1 - 0.5\, i_1 \sin \alpha_1 + 0.866 i_3 \cos \alpha_3 + 0.5 i_3 \sin \alpha_3) \qquad (2)$$

and the true power in an unbalanced three-phase circuit is $e_1 i_1 \cos \alpha_1 + e_2 i_2 \cos \alpha_2 + e_3 i_3 \cos \alpha_3$

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*See appendix of this article and "Reactive Volt-ampere Hour Meters," by J. W. West, *Ohio Electric Light Association Monthly*, Vol. VIII, No. 6.

which, with balanced voltages, becomes

$$\frac{E}{\sqrt{3}}(i_1 \cos \alpha_1 + i_2 \cos \alpha_2 + i_3 \cos \alpha_3) \qquad (3)$$

But $i_2 \cos \alpha_2 = i_1 \sin (30-\alpha_1) + i_3 \sin (30+\alpha_3)$*

$$= 0.5 i_1 \cos \alpha_1 - 0.866 i_1 \sin \alpha_1 + 0.5 i_3 \cos \alpha_3 + 0.866 i_3 \sin \alpha_3$$

Substituting this quantity for $i_2 \cos \alpha_2$ in equation (3) we have the true power to be

$$\frac{E}{\sqrt{3}}(i_1 \cos \alpha_1 + 0.5 i_1 \cos \alpha_1 - 0.866 i_1 \sin \alpha_1 + i_3 \cos \alpha_3 + 0.5 i_3 \cos \alpha_3 + 0.866 i_3 \sin \alpha_3)$$
$$= E(0.866 i_1 \cos \alpha_1 - 0.5 i_1 \sin \alpha_1 + 0.866 i_3 \cos \alpha_3 + 0.5 i_3 \sin \alpha_3) \qquad (4)$$

which, being the same as equation (2) proves that the instrument is correct when reading watts on a balanced or unbalanced load.

Fig. 9. Double Auto-transformer

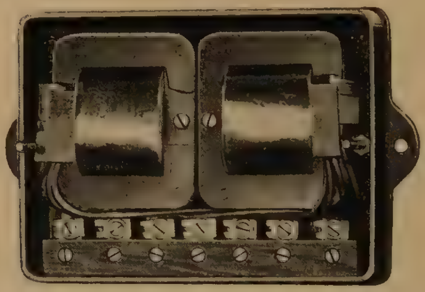

Fig. 10. Double Auto-transformer with Cover Removed

Similarly the true reactive volt-amperes from equation (1) is the quantity

$$e(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3)$$
$$= \frac{E}{\sqrt{3}}(i_1 \sin \alpha_1 + i_2 \sin \alpha_2 + i_3 \sin \alpha_3) \qquad (5)$$

But $i_2 \sin \alpha_2 = i_1 \cos (30-\alpha_1) - i_3 \cos (30+\alpha_3)$

$$= 0.866 i_1 \cos \alpha_1 + 0.5 i_1 \sin \alpha_1 - 0.866\, i_3 \cos \alpha_3 + 0.5 i_3 \sin \alpha_3 \qquad (6)$$

Substituting (6) for $i_2 \sin \alpha_2$ in (5) we find the true reactive volt-amperes to be

$$\frac{E}{\sqrt{3}}(i_1 \sin \alpha_1 + 0.5 i_1 \sin \alpha_1 + 0.866 i_1 \cos \alpha_1 + i_3 \sin \alpha_3 + 0.5 i_3 \sin \alpha_3 - 0.866 i_3 \cos \alpha_3)$$
$$= E\ 0.866 i_1 \sin \alpha_1 + 0.5 i_1 \cos \alpha_1 + 0.866 i_3 \sin \alpha_3 - 0.5 i_3 \cos \alpha_3 \qquad (7)$$

which is the true reactive volt-amperes for any condition of load. But when calibrated for reactive volt-amperes we have seen that the torque of the two-coil instrument is proportional to $0.866E(i_1 \sin \alpha_1 + i_3 \sin \alpha_3)$ which equals $E(0.866 i_1 \sin \alpha_1 + 0.866 i_3 \sin \alpha_3)$. (8)

Comparing the torque of the instrument (8) with the true reactive volt-amperes (7), it is apparent that the quantity $0.5 i_1 \cos \alpha_1 - 0.5 i_3 \cos \alpha_3$ is missing in the instrument equation. So long as the loads per phase are equal, however, this quantity has no value and the instrument will indicate correctly; but immediately the loads become unbalanced this quantity has a value which should be added algebraically to the total torque if the instrument reading is to be correct.

Comparing equation (4) for true power with equation (7) for true reactive volt-amperes it will be noted that each quantity in (4) containing the cosine of the angle has a counterpart in (7) containing the sine, and each quantity in (4) containing the sine of the angle has a counterpart in (7) containing the cosine. It is clear, therefore, that to obtain (7) the voltages must be 90 deg. displaced from those giving (4). In other words, when measuring reactive volt-amperes by the two-wattmeter method the voltages should not be in quadrature with the currents but should be in quadrature with the voltages used in measuring watts. Looking at the connections for reading reactive volt-amperes shown in Fig. 7, it is evident that voltages E_1 and E_2, while in quadrature with the currents i_3 and i_1 respectively, are themselves displaced by 120 deg. Reducing this displacement to 90 deg. brings in the effect of the quantity $0.5 i_1 \cos \alpha_1 - 0.5 i_3 \cos \alpha_3$ as required by equation (7) and as will be shown later.

Various means have been suggested for reducing this displacement from 120 to 90 deg. The simplest of all, of course, would be a middle tap in the potential transformer secondary, when potential transformers are required. However, with standard transformers having 110-volt secondaries this impresses only 95 volts on the instrument instead of 110. To obtain 110 volts from the end of one secondary to the middle tap of the other a specially wound secondary giving 127 volts would be required, but besides the middle tap at 63.5 volts an additional tap at 110 volts would have to be provided for the operation of any other instruments on the same secondary. What appears to be a good commercial solution of the problem results from the combination of a standard wattmeter with two small auto-transformers for obtaining the quadrature potential. These latter are standard equipment, and a standard wattmeter can be made to read directly and accurately, on balanced or unbalanced load, either in watts or reactive volt-amperes, depending upon whether auto-transformers are used. Since only a very low volt-ampere capacity is necessary each transformer is quite small, both being mounted in a common iron case requiring very little space for its accommodation. One of these double auto-transformers is shown in Figs. 9 and 10. Their connections are shown in Fig. 11. They are each wound to give a total of 127 volts with a 110-volt tap for the line, or potential transformer if used, and a 63.5-volt tap to give a quadrature potential of 110 volts for the reactive volt-ampere indicator. These voltages are in quadrature with the watt voltages shown in Fig. 8 and the voltage of each element of the instrument is 60 deg. displaced from its corresponding current. With this arrangement the total torque on balanced load at unity power-factor would be $2Ei \cos 60 = Ei$. But with balanced load at unity power-factor the total torque should be zero, which shows that instead of assisting each other the torques of the two elements should be in opposition. This is accomplished by reversing the connections to the potential coil of one element thereby making its torque negative. Which element should be reversed depends, as previously discussed, upon the order of rotation of the phases and upon the direction of deflection or rotation desired in the instrument.

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* See appendix.

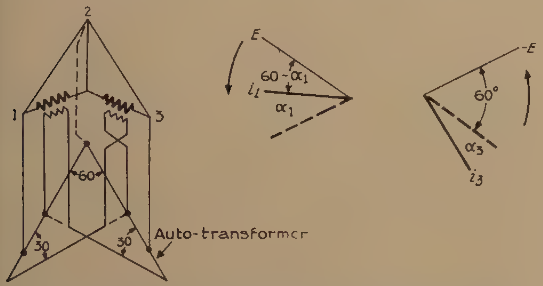

Fig. 11. Polyphase (2 Current Coil) Reactive Volt-ampere Indicator or Meter on a 3-phase 3-wire Unbalanced Load, using Auto-transformers

Fig. 12 shows a composite vector diagram of the connections shown in Figs. 8 and 11, from which it will be observed that when connected to read watts the torque is

$$W = E[i_1 \cos(30+\alpha_1) - i_3 \cos(150+\alpha_3)]$$
$$= E(0.866 i_1 \cos\alpha_1 - 0.5 i_1 \sin\alpha_1 + 0.866 i_3 \cos\alpha_3 + 0.5 i_3 \sin\alpha_3) \qquad (9)$$

while when measuring reactive volt-amperes the torque is

$$\text{R.v-a.} = E[i_1 \cos(60-\alpha_1) - i_3 \cos(60+\alpha_3)]$$
$$= E(0.5 i_1 \cos\alpha_1 + 0.866 i_1 \sin\alpha_1 - 0.5 i_3 \cos\alpha_3 + 0.866 i_3 \sin\alpha_3) \qquad (10)$$

Comparing equations (9) and (10) it will be found that each quantity in (9) containing the cosine of the angle has a counterpart in (10) containing the sine, and each quantity in (9) containing the sine of the angle has a counterpart in (10) containing the cosine. It should also be noted that the total torque under equation (10) agrees with the true reactive volt-amperes on unbalanced load as given by equation (7), and that the quantity $0.5 i_1 \cos\alpha_1 - 0.5 i_3 \cos\alpha_3$, missing in equation (8), is found in equation (10). By using a voltage in quadrature with the watt voltage we find, therefore, that the standard two-current coil wattmeter will measure true reactive volt-amperes on a three-phase three-wire system regardless of the load conditions, providing only that the voltages are balanced. Fig. 13 shows the standard connection diagram for the indicator, and Fig. 14 that for the meter, together with a watthour meter.

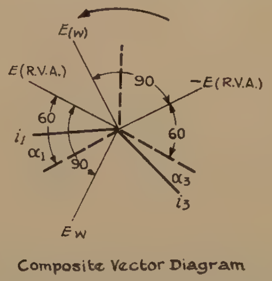

Fig. 12. Composite Vector Diagram Showing the Phase Relationship of the Watt and Reactive Volt-ampere Voltages

Three-phase, Four-wire

In a three-phase four-wire system where current is carried over the neutral wire, the equation for the currents is no longer $i_1+i_2+i_3=0$, but becomes $i_1+i_2+i_3+i_0=0$, where i_0 is the current in the neutral wire. Obviously a meter having but two current coils can measure neither the power nor the reactive volt-amperes arising from such currents, but the two-element three-current coil instrument shown in Fig. 15 can measure both these quantities with a high degree of commercial accuracy under normal operating conditions.*

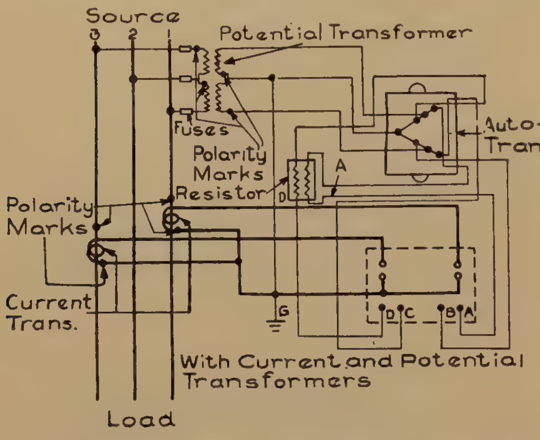

Fig. 13. Connection Diagram of a Polyphase (2 Current Coil) Reactive Volt-ampere Indicator using Auto-transformers on a 3-phase 3-wire Unbalanced Load

Two methods are available for measuring reactive volt-amperes with this meter. The first has already been discussed under Fig. 6, with the exception that on the three-phase three-wire system shown in Fig. 6 only two current transformers connected open Y are necessary, the middle coil of the instrument being connected to the resultant of the two current transformer secondaries. This is possible because on a three-phase three-wire system the sum of the three currents is always zero. On the three-phase four-wire system, however, the sum of the three currents may not be zero, and for this reason a third current transformer must be provided to take care of the current in the middle coil, which is usually connected in phase *2*. Unless on very low voltages the method shown in Fig. 6 requires the use of three potential transformers for transforming the voltage from line to neutral. Two transformers for transforming the voltage from line to line could of course be used, but as these could not also be used for measuring watts they would simply constitute an additional expense. The method has the further disadvantage of producing $\sqrt{3}$ times too much torque, necessitating special calibration or a special register. It is, however, correct for any condition of load.

A second method which is also correct for any load condition, but requires no special calibration or register, is shown in Fig. 15. This method has the advantage of using a standard instrument (indicating or integrating) and requires only two potential transformers for transforming the voltage from line to neutral. It has one disadvantage, however, in that it cannot be used without potential transformers. This is due to the fact that the voltages of the auto-transformers must be 60 deg. displaced to give the required quadrature potentials. This displacement is obtained by reversing the secondary of one potential transformer. Without the potential transformers this 60 deg. displacement cannot be obtained as the primary voltages to neutral are displaced by 120 deg.

From the vector diagram shown in Fig. 15 the watt torque is

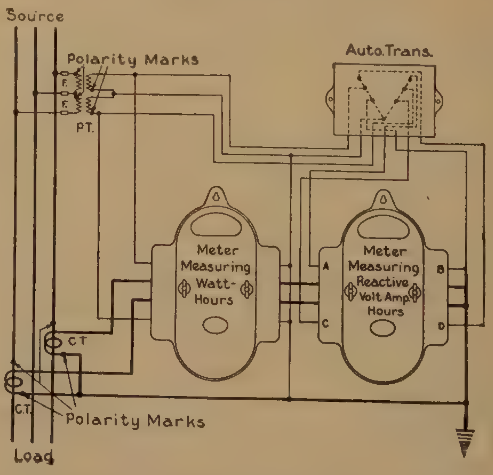
Source
Polarity Marks
F
F
P.T.
Auto.Trans.
Meter Measuring Watt-Hours
A
B
Meter Measuring Reactive Volt Amp Hours
C
D
CT
C.T.
Polarity Marks
Load

Fig. 14. Connection Diagram for a Reactive Volt-amperehour Meter on a 3-phase 3-wire Unbalanced Load, using Auto-transformers

$$W=e[i_1\cos\alpha_1+i_2\cos(60-\alpha_2)+i_2\cos(60+\alpha_2)+i_3\cos\alpha_3]$$
$$=e(i_1\cos\alpha_1+i_2\cos\alpha_2+i_3\cos\alpha_3)$$

while the reactive volt-ampere torque is

$$\text{R.v-a.}=e[i_1\cos(90-\alpha_1)+i_2\cos(30-\alpha_2)-i_2\cos(30+\alpha_2)+i_3\cos(90-\alpha_3)]$$
$$=e(i_1\sin\alpha_1+i_2\sin\alpha_2+i_3\sin\alpha_3)$$

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* For a more complete discussion of the relative accuracy of commercial meters for measuring power see "Metering on Three-phase Systems," by L. T. Robinson, GENERAL ELECTRIC REVIEW, Vol. XV, No. 6.

and this quantity, from equation (1), is the true reactive volt-amperes in a three-phase system.

Conclusion

It might be added that the single-phase reactive volt-ampere indicator is very frequently used to regulate the field strength of six-phase synchronous converters. The connections for this purpose are shown in Fig. 16. It will be noted that the instrument is connected in the six-phase circuit between the step-down transformers and the machine, thereby eliminating the effect of the transformer reactance and confining the reading to the reactive current of the machine alone. This is done because of the fact that due to unequal heat distribution in the armature the converter, when fully loaded, is not capable of improving the power-factor of the system, so that the chief purpose of the reactive volt-ampere indicator is to enable the machine to be operated at as near unity power-factor as possible, thereby restricting the heating at certain vulnerable points of the armature.

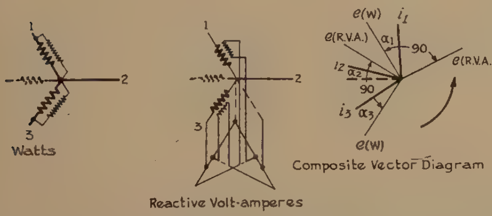

Fig. 15. Polyphase (3 Current Coil) Reactive Volt-ampere Indicator or Meter on a 3-phase 4-wire Load using Auto-transformers

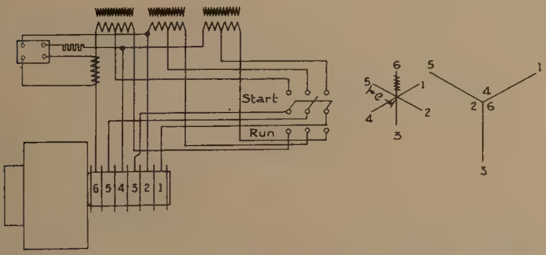

Fig. 16. Connection Diagram of a Single-phase Reactive Volt-ampere Indicator on a 6-phase 6-wire Balanced Load

From equation (1) the reactive volt-amperes in a six-phase balanced circuit is the quantity $6ei$ sin α. But the torque developed by the instrument shaft is clearly proportional to $\sqrt{3}ei$ sin α, which, however, is multiplied in the scale by $2\sqrt{3}$, thus giving a reading of $2\sqrt{3}\sqrt{3}ei$ sin $\alpha = 6ei$ sin α. The converter load is not considered sufficiently unbalanced to warrant the additional cost of a three-current-coil instrument. The multiplier in the scale of the single-phase instrument obviously precludes its use, without re-calibration, for any other purpose than the one to which it is applied.

Since there are evidently two voltages, $E_{1\text{-}5}$ and $E_{2\text{-}4}$, available which are in quadrature with the current in phase *6* it may be questioned why the voltage $E_{2\text{-}4}$ is chosen in preference to the voltage $E_{1\text{-}5}$. This may be answered by pointing out that prior to closing the starting switch the converter armature furnishes a neutral point for the three step-down transformers thus connecting them in a Y group. The voltage across phase *1-5* is then $\sqrt{3}E$, or twice the normal voltage across phase *1-5* when the machine is running. To avoid subjecting the potential coil of the instrument to this double voltage the parallel voltage $E_{2\text{-}4}$ is chosen. This voltage is zero until the converter starts and consequently imposes no undue strain upon the instrument winding.

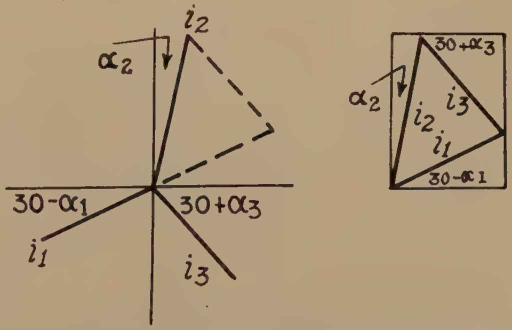

Fig. 17. Diagram Showing how Polyphase Current Vectors Form a Closed Triangle

APPENDIX

The two-wattmeter method of measuring power on a three-phase three-wire system depends upon the fact that the algebraic sum of the three currents is zero. The total torque is derived from the currents in two phases only. In many problems involving this method it is frequently desirable to find some expression for the current which does not pass through the meter in terms of the other two currents which do. Since the algebraic sum of the currents is zero the vectors representing them must form a closed triangle, as shown in Fig. 17, from which the following equations may readily be derived.

$$i_2 \sin\alpha_2 = i_1 \cos(30-\alpha_1) - i_3 \cos(30+\alpha_3).$$

$$i_2 \cos\alpha_2 = i_1 \sin(30-\alpha_1) + i_3 \sin(30+\alpha_3).$$

In this appendix it might be appropriate to add that the polyphase integrated average power-factor over a period of time may be very simply derived from the equation:

$$\frac{\text{R. v.-a.}}{W} = \tan.\ \alpha \text{ or } \frac{W}{\sqrt{W^2+\text{R.v.-a.}^2}} = \cos\alpha$$

Where α is the average polyphase angle of displacement during the period integrated, and R.v-a. and W are the respective readings taken from a reactive volt-ampere-hour meter and a watthour meter over the same elapsed time.

Similarly, measurement of volt-amperes may be obtained from the formula

$$V.\text{-}a. = \sqrt{W^2+\text{R.v.-a.}^2}$$

Passenger and Freight Locomotives for Mexican Railway Company, Ltd.

By Glen H. Walker

Railway Locomotive Engineering Department, General Electric Company

A preliminary description of the Mexican Railway electrification appeared in our March, 1923, issue, and the public exhibition test made on one of the locomotives was outlined in our February, 1924, issue. The following article primarily describes the mechanical and electrical details of the locomotive design and shows how they have been arranged to meet the service requirements of this particular electrification.—**Editor.**

The 3000-volt direct-current locomotives which have recently been completed for the Mexican Railway Co., Ltd., are of particular interest to students of railway electrification because of the fact that steam engines are being replaced by electric locomotives having approximately the same weight on the driving axles, in the ratio of two to two and one-half steam to one electric. The greater capacity of the electric locomotive equipment is due to the higher continuous capacity at increased speeds and the much greater percentage of time in service as compared with steam locomotives. The comparison between steam and electric operation in this case is also unusual in that the steam locomotives are double ended and are capable of operating equally well in either direction. The elimination of turn-table expense, therefore, cannot be credited to electrification as is usually the case.

The order placed with the International General Electric Co. includes ten 150-ton 3000-volt locomotives as well as all other electrification equipment for the 30-mile division between Orizaba and Esperanza. This section is known as the Maltrata Incline and includes the heaviest grades on the line between Vera Cruz and Mexico City. The maximum grade on this section is 5.25 per cent and the ruling grade is 4.7 per cent. The curvature is unusually heavy for practically the entire distance and there are a large number of tunnels.

Service

The locomotives will be used in both freight and passenger service between Orizaba and Esperanza. Freight trains of 700 tons weight will be taken up the grade with two locomotives, one at the head and one at the rear of the train. Trains of about the same weight will be brought down the grade with one locomotive by regenerative electric braking. Speeds both up and down grades for freight trains will average about 15 m.p.h.

All but an occasional passenger train can be taken over the grades by a single locomotive. For passenger trains requiring more than one locomotive, two units will be used operating at the head end under the control of one engineman. As it is considered unsafe to run trains down these grades and around the sharp curves at a greater speed than 20 m.p.h., the same gear ratio will be used for passenger service as for freight service. The speeds of the passenger trains will average about 18 to 20 m.p.h. both up and down grades, although the locomotives can operate at a maximum speed of 40 m.p.h.

The locomotives are of the twin-geared

articulated-truck type having the characteristics and dimensions given in Table I.

Mechanical Features

A single cab is mounted on two equalizer frames which in turn are carried upon three two-axle articulated trucks. A motor is geared direct to each axle with twin, cushion-type gears.

The cab is of the box type, built up of ⅛-in. sheet steel, riveted to structural framework, on a platform of structural steel longitudinal and cross sills, stiffened by bolster bars and a ⅜-in. steel floor plate. The cab is 47 ft. 6 in. long by 10 ft. wide and divided into an apparatus compartment and an engineman's cab 5 ft. long by 10 ft. wide at each end. The apparatus compartment houses the high-tension control apparatus and the auxiliary machinery. Doors and windows are located

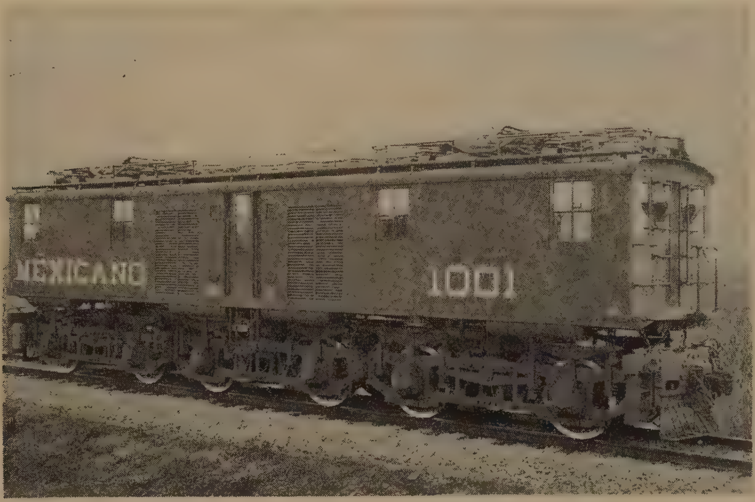

Fig. 1. One of the 150-ton 3000-volt Direct-current Locomotives built for the Mexican Railway Co. Ltd.

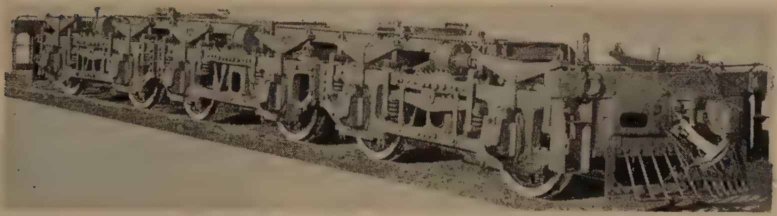

Fig. 2. Running Gear of 150-ton Articulated Type Locomotive

TABLE I

Electrical Data	
Nominal voltage of system	3000 v. d-c
Tractive eff., 1 hr. blown (3000 v.)	54,000 lb.
Speed at 1 hr. rating, full field	19 m.p.h.
Total horsepower, 1 hr	2736
Tractive eff., cont. 3000 v., full field	48,500
Speed at continuous rating, 3000 v.	19.5 m.p.h.
Total horsepower, continuous	2520
Number of motors	6
Type of motors	GE-278-A-1500/3000 v.
Gear ratio	90/18–5.00
Tractive eff. at 30 % tract. coef	92,700 lb.

Mechanical Data	
Track gauge	4 ft. 8½ in.
Wheel arrangement	04440
Diameter of drivers	46 inches
Number of driving axles	6
Total wheel base	40 ft. 6 in.
Max. rigid wheel base	9 ft. 2 in.
Width overall	10 ft. 1½ in.
Height over trolley locked down	15 ft. 2 in.
Length inside knuckles	52 ft. 11 in.

Weights

Total weight on drivers	309,000 lb.	Elec. and air brake equipment	135,000 lb.
Dead weight per axle	12,150 lb.	Mechanical equipment	174,000 lb.

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to provide light and access to the cabs and apparatus compartment. Louvers are located on each side of the side doors to admit air to the cab for the blowers.

The three trucks have steel side frames to which the end frames carrying the draft gear and articulated joints are bolted. The cab structure and equalizer frames are carried on center plates on the transoms of the trucks. The transoms are bolted to the truck frames at their midpoint and the whole is carried on equalized semi-elliptic springs as has been satisfactorily used on locomotives for the Butte, Anaconda & Pacific, the Chicago, Milwaukee & St. Paul, the Baltimore & Ohio, and others. Buffing and hauling stresses are carried through the side frames and the articulated joints.

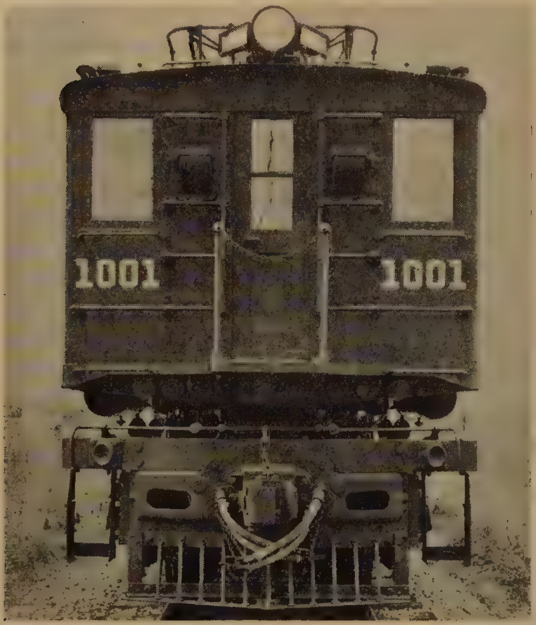


Fig. 3. End View of Mexican Railway Co. Locomotive

The leading and trailing trucks are equipped with Miner Friction draft gear and Simplex couplers with 5-in. by 7-in. shank, 9⅛-in. butt, and 9-in. solid knuckle. The couplers are located a distance of 34½ in. above the rail head.

Motors

To each of the six axles there is geared a box-frame, twin-geared, commutating-pole, GE-278-A-1500/3000-volt, railway-type motor with forced ventilation. These motors are designed to operate two in series on 3000 volts or with 1500 volts per motor, but each is insulated for 3000 volts to ground. Each motor is supported on its axle by suspension bearings and on the transom by a spring-nose support giving a clearance of 4¼ in. under the gear case with new wheels and axle linings. An 18-tooth forged steel pinion is mounted on each end of the armature shaft which meshes with a 90-tooth cushion-type gear on the axle. The cushion-type gear is designed to permit a small movement of the rim about the gear center which tends to equalize the stresses in the gears and pinions and to minimize the shocks on the teeth.

An unusual feature of this locomotive design is the provision for removing the motor, wheels, and axle from any of the trucks without lifting the cab. In the usual type of geared locomotive, the cab must be lifted sufficiently to remove the truck so that head room can be obtained for the purpose of lifting out the motor. The truck of the Mexican Railway Co.'s locomotive is so constructed that by first disconnecting the motor leads and then jacking up the motor and side frames, the wheels and axle and finally the motor can be dropped into a pit. Practically the only parts removed are the pedestal tie bars, the journal box shoes, and the journal boxes.

Auxiliary Machinery

The auxiliary machinery consists of a 3000/1500-volt dynamotor which has a 4-kw. 65-volt control generator mounted on a shaft extension; a 1500-volt regenerative exciter set; two 1500/3000-volt motor-driven blowers; and two 1500/3000-volt air compressors. The dynamotor provides 1500-volt power for oper-

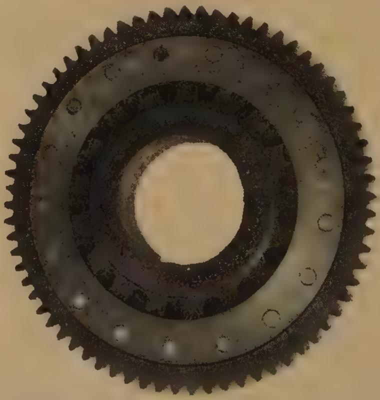


Fig. 4. Flexible Gear used on Mexican Railway Co. Locomotive

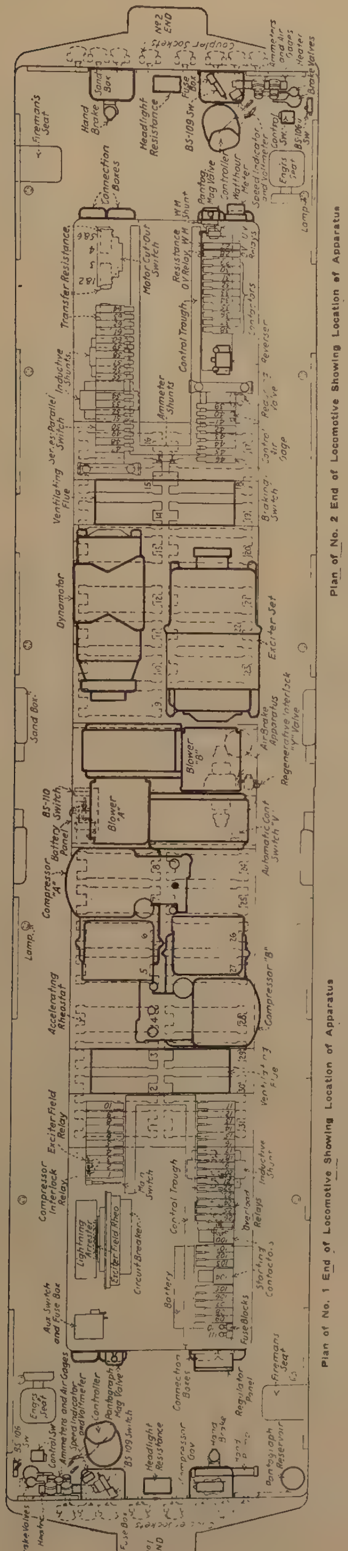


Fig. 5. Diagram showing Location of Apparatus on Mexican Railway Co. Locomotive

ation of the blowers, compressors, and the regenerative exciter set. The two blower motors and the two compressors will normally be operated in series across 3000 volts with their mid-points connected to the mid-point of the dynamotor for equalization. The regenerative exciter set will be operated between the 1500-volt point on the dynamotor and ground. If it is not required to operate the blowers at their maximum capacity, they may be connected in series and operated from the 1500-volt dynamotor bus to ground.

The control generator mounted on the dynamotor shaft extension furnishes current at 65 volts for lights, headlights, foot warmers, control circuits, and for charging the storage battery.

The two air compressors are of the two-stage horizontal-cylinder type and have a total piston displacement of 150 cu. ft. per min. when delivering air against 130-lb. pressure and operating two in series on 3000 volts.

The scheme of auxiliaries chosen for this locomotive provides means for operating one compressor or one blower from the 1500-volt dynamotor bus in case of failure of the other machine. It also provides means of operating the compressors and blowers in case of failure of the dynamotor which could not be done if low-voltage auxiliaries were operated from a 3000-volt motor-generator set. A further advantage is that a dynamotor is inherently a stable machine and not subject to flashing due to short circuits and sudden changes in trolley voltage.

Air Brake

The air brake is double-end, straight and automatic Westinghouse equipment including air signals. This equipment is arranged for double-heading locomotives, and provision is made to prevent application of air brakes on the locomotive during regenerative braking although the brakes may be applied on the train. This feature enables a single locomotive to bring a much heavier train down grade under the control of regenerative braking and air brakes than could be brought down under the control of regenerative braking alone. In case of an emergency application of the air brakes during regenerative braking, regeneration is automatically shut off allowing the air brakes on the locomotive to apply in the usual manner. Connections of the air lines from the cab to the trucks are made through Barco flexible metallic joints.

Control

The locomotives are equipped with electro-pneumatic control for non-automatic, multiple-unit operation. A master controller is located in the engineman's cab at each end of the locomotive and arranged to give 15 accelerating steps, one full-field running step, and two reduced-field running steps with six motors in series in one group; nine accelerating steps, one full-field running step and two reduced-field running steps with three motors in series in two parallel groups; and seven accelerating steps, one full-field running step and two reduced-field running steps with two motors in series with three groups in parallel. This gives a total of nine running points which for a given tractive effort of 50,000 lb. and 2700 volts line correspond to speeds of approximately 5.4, 6.0, 6.75, 11.4, 12.8, 14.2, 17.4, 19.6, and 21.6 m.p.h.

Fig. 6. View of Completed 3000-volt Overhead Line Construction in Mexican Railway Co.'s Electric Zone

Regenerative braking on the down grades is accomplished by exciting the fields of the traction motors by the variable-voltage regenerative exciter. Fifteen regenerating steps are provided on the master controllers for each of the three motor groupings. These permit continuous regeneration at values of speed and braking effort within the safe operating limits of the motors.

The main motor circuits are protected by a high-speed circuit breaker placed in the main circuits ahead of all accelerating contactors, etc. This breaker serves as a line breaker as well as to give overload and short-circuit protection. On overloads it trips out due to the action of overload relays and on short circuit it opens on a sudden rise in the current flowing through it.

The auxiliary apparatus is controlled by electro-magnetically operated contactors which are actuated by push-button switches within reach of the engineman at either operating position.

Current is collected from a centrally located overhead conductor through one or both of two slider pantograph trolleys located on the roof of the locomotive, one at each end. These trolleys have a range of 15 ft. 5 in. to 24 ft. above the rail. They are raised and held against the wire by air pressure and are retracted by gravity when the air pressure is released. Air is admitted to or exhausted from the trolley cylinders by a magnet valve which is operated by a push-button switch at the operating position. The engineman can raise or lower either or both trolleys by these switches at either position.

The locomotives are equipped with air operated whistles, bell ringers, and sanders which are controlled by valves at the engineman's position. Ammeters, a voltmeter, and a speed indicator, as well as the usual air gauges, are mounted on panels within the engineman's view.

Fig. 7. Another View of Completed 3000-volt Overhead Line Construction

Arrangement of Apparatus

The apparatus compartment is divided up into a rheostat compartment and two control apparatus compartments. The rheostat compartment extends each way from the center of the cab about one-half the length of the apparatus compartment and is approximately 3 ft. high. Near each end a ventilating flue extends from this compartment to ventilators on the roof which serve to carry off the heat generated by the rheostats.

The roof of the rheostat compartment is insulated against heat and used as a shelf upon which the auxiliaries are mounted and conduits are run carrying cables between the control compartments and from the control compartments to the taps on the rheostats. The latter cables are carried from the conduits through the roof of the rheostat compartment in porcelain bushings.

The location of the auxiliaries in the middle and on top of the rheostat compartment makes them very accessible for inspection from the side aisles and keeps the noise of the running machines out of the engineman's cab.

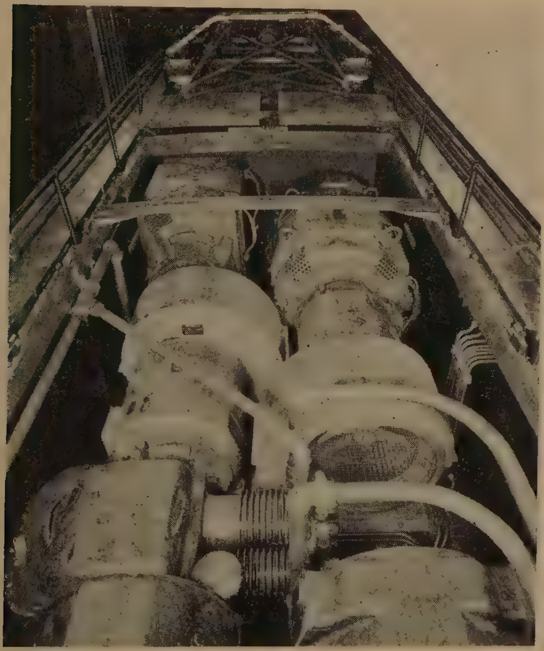


Fig. 8. View Looking Down into Auxiliary Machinery Compartment

The control apparatus compartment on No. 1 end contains the main switch, high-speed circuit breaker, lightning arrester, other protective apparatus, and some of the accelerating contactors. These pieces of apparatus are located so that there is a center aisle in the compartment giving very easy access. This aisle is entered from the engineman's cab and is on the same level.

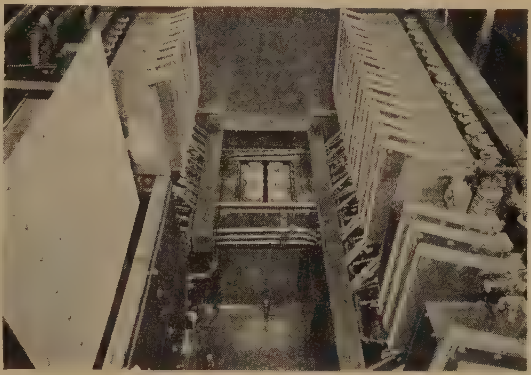


Fig. 9. View Looking Down into Control Apparatus Compartment No. 1 End

The control apparatus compartment on No. 2 end is similar in arrangement to that on No. 1 end and contains the cam switches for grouping the motors for the different motoring and regenerating combinations, the reverser, the motor cut-out switches and the remainder of the accelerating and field-reducing contactors.

The high-voltage connections to the apparatus in both compartments are made at the back and are accessible by removing compartment covers into the side aisles. The low-voltage control connections are made at the front of the apparatus and the wires are carried in a control trough running in front of the apparatus.

The mechanical portion of these locomotives was built by the American Locomotive Company at its Schenectady Works. The equipment was manufactured by the General Electric Company in its various plants and the installation of equipment and tests are being made at the Erie, Pa., plant of the General Electric Company. The ten locomotives will be shipped overland by way of the Mexican National lines to Mexico City.

Charles A. Coffin Foundation Awards

By R. D. Owen

Publicity Department, General Electric Company

On previous occasions we have told of the awards made under the Charles A. Coffin Foundation in the lighting industry and in the railroad industry. On this occasion the author gives an account of the awards recently made to the employees of the General Electric Company.—Editor.

The adequate recognition of the services of industrial workers has long been a problem. Many methods have been tried with varying degrees of success. A new way of according this recognition was put into effect when the Charles A. Coffin Foundation was established by the General Electric Company, and the first awards to employees of the Company have just been made. Forty-seven men and one woman out of 80,000 employees were selected because of their achievements during the year and were presented publicly with a certificate of merit and a cash award.

So far as is known, this is the first time that employees in any industry, particularly workers in the shops, have been publicly recognized by management for work they have done in the industry outside their ordinary duties. Engineers and research workers have gained public distinction by their achievements, but the man in the shop, as a rule, has seldom become known to other than a few of his immediate associates for work that may have had an almost revolutionary effect in the branch of industry in which he was engaged.

But the Charles A. Coffin Foundation awards were made in such a way that they became a matter of public interest, and the shopmen who received them found—the day after they had received them from the works managers—that the newspapers of their own town had thought the matter important enough to tell of what they had done and perhaps to publish their pictures. Their achievements appeared beside those of engineers prominent in their profession, of commercial men who sold the products produced by the engineers and the shop workers; it was a recognition by the community of work well done.

Many in the National Lamp Works, for instance knew that Loris E. Mitchell and Arthur J. White, both young men, had finally found a way to make tipless Mazda lamps, something for which engineers had sought for years. Their work was appreciated and acknowledged, but the Foundation award made it possible to give these men the outside recognition which was their due from those among whom they lived. Mitchell and White are known in Cleveland now as the men who took the tips off lamps.

The awards placed them in the same category with William LeRoy Emmet, the distinguished engineer who developed the mercury vapor system. Mr. Emmet's work has been heralded all over the country as a remarkable contribution to fuel economy, aside from its ingenious engineering features. Mitchell and White are foremen, but they met with Emmet on the same ground of achievement for the benefit and progress of the electrical industry.

The record of the many accomplishments for which awards were given makes one realize the ingenious application of intelligence, technical skill and dogged persistency which creates, builds and puts into human service the machines so necessary for the comfort, progress and industrial development of our country. The Foundation has shown in its first year that to those who strive always to see in their work something new, something worthy of all their efforts, there comes a day when the mind leaps to seize the opportunity presented, leaps to claim and fashion an idea and make it serve not only him who gave it birth but the community at large. One gets a glimpse of the daring initiative and human effort so often concealed behind the rows of vast buildings and dwarfed by mighty machines.

It is this which gives so great a variety to the many achievements which were recognized. They ranged from a revolutionary engineering accomplishment, like that of Mr. Emmet's, to an improvement in methods of keeping records of relations with customers, devised by a stenographer, Isabelle Douglas Barron. And nearly all of them were for accomplishments outside their daily work, for the solution of problems which they had observed and longed to solve, even in a strange field.

Not only was technical achievement recognized. Those attributes of character which mark a man among his fellows were shown to play as important a part in industry as skill and initiative. Guy Bellows and John B. Cox in their railway work in Brazil and Mexico showed coolness and tact and integrity which stamped them as something more than salesmen and engineers. It was a remarkable tribute to character when the Mexican Railway asked Mr. Cox to represent them in their dealings with the Company. Oliver J. Nicklaw, an expert armature winder, who went to India to help rebuild some generators, not only did his work well, but by his personal conduct and character won the respect and admiration of everyone with whom he dealt.

There were 150 nominations sent in for consideration by the committee which made the awards. Of these, 79 were selected for final analysis, and 48 finally chosen. There were 10 shop workers selected for awards, 10 foremen, 16 engineers, six commercial men and one woman, and five administrative employees. Each was awarded a certificate of the Foundation in recognition of his accomplishment, and a sum of money.

Those who received awards were:

SHOP WORKERS

Paul Johnson Durrette, Panel Assembler, Switchboard Department, Schenectady. Mr. Durrette suggested that the chalked wiring diagrams on the back of switchboard panels be photographed instead of sketched. His suggestion eliminated unnecessary labor and secured greater accuracy.

John Flaws, Machinist, Edison Lamp Works, developed vacuum tube grid winding by machine, increasing accuracy of manufacture and effecting economies.

Gustave D. Holmberg, Annealing Works, Pittsfield Works, suggested application of rust to grey iron castings in order to prevent formation of hard scale when annealed.

Vincent Jarman, Machinist, Edison Lamp Works, developed, in collaboration with Louis Wenner, method and equipment for the accurate spacing, cutting and forming of continuous coiled filaments.

John Edward Mullarkey, Steam Fitter, Moulded Insulation, Schenectady. Mr. Mullarkey modified valves and changed piping used on steam and waste water lines leading to and from moulds in order to obtain quicker heating and cooling of moulds.

Francis Rippl, Machinist, National Lamp Works, developed, with J. T. Pagen, a basing, soldering and flashing machine.

Daniel E. Simpson, Machinist, Switchboard Department, Schenectady, invented a waterproof fuse holder sought by engineers for a long time. Mr. Simpson made a sketch of a design which was accepted.

J. G. Smith, Automatic Machine Operator, West Lynn, devised method for more efficient operation in filling potential coils with iron laminations.

William J. Streader, Maintenance of Equipment, Wire and Cable Department, Schenectady, has been steadily vigilant in overcoming difficulties in the manufacture of high tension cable. He has devised many valve improvements.

Hubert Wheeler, Wire Enameller, River Works, Lynn, improved method of enamelling 0.003 copper wire.

FOREMEN

E. H. Ballard, Brass Foundry, River Works, Lynn, advocated and caused to be installed many safeguards to health and physical welfare which have gone far to make for excellent working conditions in the foundry. He has established the finest relationship with his workmen.

Loris Edwin Mitchell, National Lamp Works, with Arthur James White developed the method and type of equipment which make possible on a commercial scale the manufacture of tipless incandescent Mazda lamps.

Archibald Wilson Nisbet, Heat and Light Department, Schenectady, has brought the Schenectady Works Power House to a very high degree of efficiency. He has been extremely resourceful in problems of applying steam to manufacturing processes.

Carl A. Salmonsen took charge of the Punch Press Department in the Schenectady Works in 1923 when conditions were very unsatisfactory. Under his leadership working conditions have been materially improved and without change in piece rate the average earnings of the department have gone up 20 per cent.

William B. Shanaberg, Edison Lamp Works, directed and taught operatives during development of unit machine operation. Also achieved successful results in similar work in France and Italy.

Wesley E. Stetson, River Works, Lynn, organized with remarkable success a department for manufacture of an absolutely new line of marine appliances, calling for a greater degree of exactness and accuracy than anything before attempted on a large scale in the Works.

Frederick M. Vogel, West Lynn Works, developed a low bench and model chair which have been introduced into various parts of the factory with excellent results, and which have been enthusiastically received by the workers despite the fact that they first opposed them.

Louis Wenner, Edison Lamp Works, developed in collaboration with Vincent Jarman, method and equipment for the accurate spacing, cutting and forming of continuous coiled filaments.

Arthur James White, National Lamp Works, developed, with Louis E. Mitchell, the method and type of equipment which make possible on a commercial scale the manufacture of tipless incandescent Mazda lamps.

Louis Wulff, Pittsfield Works, developed method of using scrap material in place of expensive wood, pressboard or hard fiber, as coil supports in transformers.

ENGINEERS

Theophilus F. Barton, Central Station Engineering Department, Schenectady, brought about improvements in motor-generator sets for use in substations for transforming the alternating-current supply in big cities to direct current for the Edison three-wire system.

L. F. Blume, Transformer Engineer, Pittsfield Works, developed method of regulating transformer voltage under load.

Wilfred Campbell, Mechanical Research on Turbine Engineering, Schenectady, did important work in the correction of turbine wheels and buckets for dangerous vibration. He made it possible to predetermine a close approximation of wheel and bucket behavior at the time the design is laid out.

W. B. Cordes, Marine Superintendent, New York Office, displayed great presence of mind and quick action in preventing accident to crowded electrically-driven ferry boat.

Alvarado LeRoy Ellis, Assistant Director, Thomson Laboratories, Lynn. In recognition of work in collaborating with Edward M. Hewlett and associated engineers in developing a new type of marine appliance of far-reaching importance.

William LeRoy Emmet, Consulting Engineer, Schenectady. In recognition of his distinguished achievements in solving scientific and practical problems pertaining to the generation of electrical energy which have resulted in its more general use on account of greater availability and lessened costs and in special recognition of the mercury vapor system.

William F. Frisch, Manufacturing Engineer, Fort Wayne Works, developed method and machine for automatically testing transformers or other electrical devices, thus eliminating dangers and securing economies.

Edward M. Hewlett, Engineer, Switchboard Department, Schenectady. In recognition of his outstanding accomplishment in conceiving the idea of a new and important type of marine appliance and in collaboration with associated engineers in its development.

M. L. Kennedy, Erecting Engineer, Boston Office, for his services in rendering valuable assistance to and winning the high regard of a customer under exceptional circumstances.

Paul A. Kober, Chemist, Edison Lamp Works, developed commercialization of the use of dyes which, subjected to specific temperatures, become fixed in color and are therefore of the greatest value as temperature indicators. This is of great importance in ascertaining what takes place within sealed-in Mazda lamps.

Edwin J. Murphy, Engineer, Searchlight Department, Schenectady. In recognition of work in collaboration with Edward M. Hewlett and associated engineers in developing a new type of marine appliance of far-reaching importance.

Oliver J. Nicklaw, Expert Armature Winder, while representing Contract Service Department, Schenectady, rendered services in India in doing more than he was supposed to do, and in making a friend of a customer as well as all those he came in contact with.

Christian Steenstrup, Supervisor of Mechanical Research Department, Schenectady, has worked for years in applying hydrogen brazing to manufacturing processes. The results have been of great value.

John Franklin Tritle, Electrical and Mechanical Design, Railway Equipment Engineering Department, Schenectady, invented and perfected a new and unique type of high speed circuit breaker. This will be an important factor in the solution of the high-voltage direct-current railway electrification problem.

Ludwig S. Walle, Switchboard Engineering, Schenectady, devised a centrifugal tripping mechanism, previous tripping devices having been unsatisfactory. It is both novel and of great commercial value.

Waldo W. Willard, Switchboard Engineering Department, Schenectady. In recognition of work in collaboration with Edward M. Hewlett and associated engineers in developing a new type of marine appliance of far-reaching importance.

COMMERCIAL

Isabelle Douglas Barron, stenographer, Pittsfield Works, originated while doing stenographic work, condensed record of relations with customers.

Guy Bellows, Field Engineer, Railway Engineering Department, Schenectady, undertook the installation of the Paulista Railway in Brazil and carried it through under difficult local conditions. He had to meet all engineering and sales problems.

John B. Cox, Field Engineer, Railway Engineering Department, Schenectady, carried on all the engineering and commercial negotiations leading up to a contract for ten 150-ton locomotives and auxiliary equipment for the Mexican railways.

W. J. Delehanty, Salesman, San Francisco Office, for promptly restoring to service electrical equipment of the Pacific Portland Cement Company, threatened with a shut-down of long duration.

C. C. McDowell, Salesman, Buffalo Office, first in our Company to conceive and recommend the practice of putting up in standard packages small renewal parts for compensators and similar devices.

J. O. Roser, Central Station Department, Pittsfield Works, suggested scheme whereby sources of business secured in distribution and small power transformers could be analyzed and studied.

E. W. Smith, Assistant Manager, St. Louis Office, for exemplifying the highest type of commercial ethics in his relations with members of the electrical industry.

ADMINISTRATIVES

Dr. W. H. Bunn, Works Physician, National Lamp Works, Youngstown Division. Dr. Bunn by his intelligent analysis and correction of conditions in the Youngstown Works did a notable work in safeguarding the health of workers in that plant. His work has been praised by one of the most critical health organizations in the country as being of outstanding importance.

J. W. Crise, Works Accountant, Fort Wayne Works, devised improved method of inventory control.

Albert Depuy, Duplicator Service, General Office, Schenectady. Successfully organized a central duplicator service bureau and applied the duplicator process to replace more costly forms of producing copies of matter.

Milton Cash Jones, Supervisor, Tabulating Section, Statistical Department, Schenectady, worked out the application of the electrical printing tabulating machine to a section of our most detailed tabulating work while this machine was still in an experimental stage.

A. J. Pilon, Cost Clerk, Pittsfield Works, suggested special shear for separating base from rim for the new steel tank distribution transformers. It will result in large economies.

These awards to employees complete the first year of the active existence of the Charles A. Coffin Foundation, established for the purpose of encouraging and rewarding service in the electrical field. The results in the first year have, even to a greater extent than was anticipated, focused attention on achievements which otherwise might have been known to only a small group, and in this way have tended to raise to a constantly higher level the standards of the electrical art.

There are four groups to which awards have been made bv the Foundation—public utilities, electric railways, graduates of American Colleges and technical schools, and employees of the General Electric Company.

The Charles A. Coffin medal for service to the public and the industry in the public utility field was won by the Southern California Edison Company.

The Charles A. Coffin Medal for distinguished contribution to public service in the electric railway industry was won by the Chicago, North Shore and Milwaukee Railroad. Six fellowships were awarded to college graduates doing research work. These awards to employees of the Company are the last of the series.

The committee which made the employees' awards was composed of: Gerard Swope, chairman, J. G. Barry, A. G. Davis, H. F. T. Erben, A. H. Jackson, G. F. Morrison, C. E. Patterson, F. C. Pratt, and F. S. Terry.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Brakes, Dynamic

Novel Application of Dynamic Braking on Large Slope Hoist. McNeill, R. W.
Coal Age, Jan. 10, 1924; v. 25, pp. 35-39.
(An illustrated description of equipment used at a Lehigh Valley Coal Company mine, Shenandoah, Pa.)

Circuit Breakers

High-Voltage Circuit Breakers. Copley, A. W.
A. I. E. E. Jour., Jan., 1924; v. 43, pp. 17-18.
(Brief description of equipment used by the Southern California Edison Company.)

Oil Switch Brush Velocities. Garnett, A.
Met.-Vick. Gaz., Nov., 1923; v. 7, pp. 410-412.

Cranes, Electric

Direct or Alternating Current for Overhead Traveling Cranes. Laing, William L.
Am. Mach., Jan. 24, 1924; v. 60, pp. 133-134.
(Advantages and disadvantages, selection of proper motor, etc.)

Detectors, Vacuum Tube

Alkali Vapor Detector Tubes. Brown, Hugh A. and Knipp, Chas. T.
A. I. E. E. Jour., Jan., 1924; v. 43, pp. 26-32.
(Describes the characteristics of radio frequency detectors when primed with a potassium-sodium alloy.)

Electric Control Systems

Control and Switching of High-Pressure Distribution Systems. Hunter, P. V.
Elec. Rev., Jan. 11, 1924; v. 94, pp. 72-74.
(Abstract of paper before the Société Française des Électriciens. Serial.)

Electric Distribution

Calculating Distribution Lines. Burt, Austin.
Elec. Wld., Feb. 2, 1924; v. 83, pp. 232-233.
("Rough-and-ready rule.")

Electric Heating

Place of Electricity in the General Heating Field. Hynes, Lee P.
Am. Soc. Heat & Vent. Engrs. Jour., Jan., 1924; v. 30, pp. 17-24.

Electric Heating, Industrial

Electrical Energy Economical for Heat Treating. Collins, E. F.
Am. Soc. St. Treat. Trans., Jan., 1924; v. 5, pp. 67-81.
(Presents data on relative operating costs of electric and fuel-fired heat treating furnaces.)

Electric Power

Superpower in Its Relation to Industry and the Railroads. Murray, W. S.
N. E. L. A. Bul., Jan., 1924; v. 11, pp. 3-7.
("An address before the Philadelphia Chamber of Commerce.")

Electric Transmission

Superpower Transmission; Economies and Limitations of the Transmission System of Extraordinary Length. Thomas, Percy H.
A. I. E. E. Jour., Jan., 1924; v. 43, pp. 3-17.
("A study of the transmission of very large blocks of power for extraordinary distances.")

Electrical Machinery—Parallel Operation

Parallel Operation of Alternators Driven by Internal Combustion Engines.
Met.-Vick. Gaz., Nov., 1923; v. 7, pp. 398-403.

Electrical Machinery—Temperature

Explosive Limits of Gas Mixtures. Asch, E. (In German.)
Zeit. Tech. Physik, Nov. 12, 1923; v. 4, pp. 468-471.
(Pertains to gases used in the cooling of electrical machinery.)

Electricity—Applications—Petroleum

Electricity in the Oil Fields. Taylor, W. G.
Elec. Wld., Feb. 2, 1924; v. 83, pp. 229-231.
(Abstract of a paper before the American Petroleum Institute.)

Gears, Helical

Uggla System of Helical Gearing for Electrical Motors.
Commonwealth Engr., Dec. 1, 1923; v. 2, pp. 178-179.
(Illustrated descriptive article. Points out advantages of helical gearing over spur or worm gearing for reducing speed of an electrical motor.)

High Voltage

High-voltage Phenomena. Peek, Jr., F. W.
Franklin Inst. Jour., Jan., 1924; v. 197, pp. 1-44.
(Well-illustrated account of G-E tests of supervoltage phenomena.)

Hydroelectric Development

Davis Bridge Power Project to Develop 60,000 H. P. Eaton, A. C.
Engng. News-Rec., Jan. 24, 1924; v. 92, pp. 142-146.
(Describes the hydraulic features, chiefly, the New England Power System project on the Deerfield River, near Readsboro, Vt.)

Mercury Turbines

Emmet Mercury Vapour Plant.
Engr., Jan., 18, 1924; v. 137, pp. 65-68.
(Illustrated account of the construction of the Hartford installation.)

Power Plants, Electric

"The Electricity Supply Business and Its Future." Mitchell, R. B.
I. E. E. Jour., Dec., 1923; v. 62, pp. 40-46.
(A discussion of the central station industry as it exists in England.)

Waukegan 400-Lb. Plant Operating.
Elec. Wld., Jan. 12, 1924; v. 83, pp. 79-86.
(Illustrated description of the Waukegan, Ill., plant of the Public Service Company of Northern Illinois. Same plant described in *Power Plant Engineering*, Jan. 15, 1924. pp. 119-126.)

Radio Broadcasting

Broadcasting in the British Isles. Burrows, Arthur R.
Wireless Age, Feb., 1924; v. 11, pp. 24-26, 41, 67.

Radio Engineering

Dynamic Model of a Valve and Oscillating Circuit. Clinker, R. C.
I. E. E. Jour., Jan., 1924; v. 62, pp. 125-128.
(Short paper describing a model constructed by the use of strings, pulleys, springs, etc.)

Loud Speakers. Sandeman, E. K.
Wireless Wld. & Radio Rev., Jan. 23, 1924; v. 13, pp. 521-524.
(On the theory and the characteristic curves. Serial.)

Radio Stations

Wireless Section: Chairman's Address. Shaughnessy, E. H.
I. E. E. Jour., Dec., 1923; v. 62, pp. 51-57.
(Chairman of the Wireless Section, Institution of Electrical Engineers, discusses British radio developments, particularly the Leafield high-power station.)

Radiotelephony

Engineering Trans-Atlantic Radio Telephony.
Radio News, Feb., 1924; v. 5, pp. 1052-1054, 1156-1157.
(A relatively non-technical account of the theory of trans-atlantic transmission.)

Railroads—Electrification

Electrification of Foreign Railways Including Recent Developments and Projects. IV. Germany. Smith, S. Parker.
Wld. Power, Jan., 1924; v. 1, pp. 44-51.

Ship Propulsion, Electric

Diesel-Electric Fruit-Carrying Ships "La Playa," "La Marea" and "La Perla."
Shipbuilder, Jan., 1924; v. 30, pp. 29-44.
(Well-illustrated description of propelling equipment.)

Machinery Trials, Coast Guard Cutter Modoc. Newman, Q. B.
Mar. Engng., Feb., 1924; v. 29, pp. 94-105.
(An account of tests of a vessel equipped with G-E turbine-electric drive. Paper read before the Society of Naval Architects and Marine Engineers.)

Steam

Properties and Utilization of High-Pressure and Super-Pressure Steam. Josse, E. (In German.)
V. D. I. Zeit., Jan. 26, 1924; v. 68, pp. 65-71.
(On the fundamental theories of high-pressure steam and its use in turbines, etc.)

Steam Turbines

Impulse and Reaction in Steam Turbines. Hodgkinson, Francis P.
Power, Jan. 29, 1924; v. 59, pp. 174-175.
(An explanation of the meaning of the two terms. A succeeding article will discuss changes in pressure and velocity.)

Steel—Electrometallurgy

Quality of Electric and Open-Hearth Steels. De Maré, B. E. L.
Iron Age, Jan. 31, 1924; v. 113, pp. 379-381.

Strength of Materials

Strength Properties of Wrought Iron, Mild Steel and Nickel Steel at High Temperatures. Carrington, H.
Engng., Jan. 18, 1924; v. 117, pp. 69-71.
(Presents test results.)

Trolley Wire

Sleet Formation on Trolley and Transmission Lines. Luke, G. E.
Elec. Trac., Jan., 1924; v. 20, pp. 18-19.
(Short article giving the results of tests.)

Vibrations

Vibration Problem in Engineering. Soderberg, C. R.
Elec. Jour., Jan., 1924; v. 21, pp. 39-43.
(Reviews the fundamentals underlying the problems of vibration, its general effects and prevention. Serial.)

Water Turbines

Turbines at Raanaasfoss Power Station, Norway. Thoresen, Hallgrim.
Engr., Jan. 18, 1924; v. 137, pp. 60-63.
(Illustrated description of water turbines of the Karlstad and the Voith types, as installed in a large Norwegian hydro-electric plant. Serial.)

NEW BOOKS

Boiler Chemistry and Feed Water Supplies. Ed. 2. Paul, J. H. 252 pp., 1923, N. Y., Longmans, Green & Co.

Direct-Acting Steam Pump. Ed. 2. Nickel, Frank F. 258 pp., 1923, N. Y., McGraw-Hill Book Co., Inc.

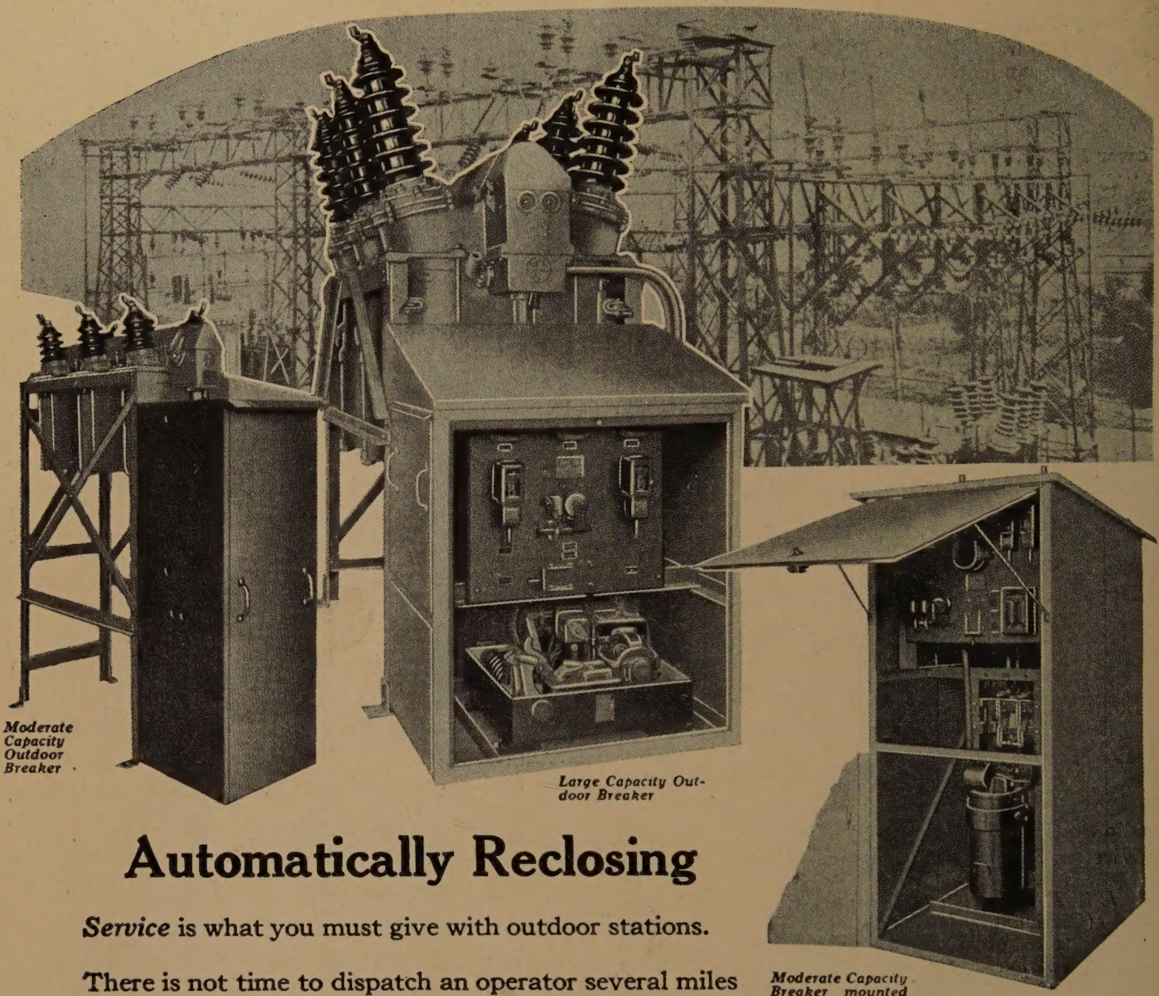
Engine-Room Practice. Ed. 11. Liversidge, John G. 429 pp., 1923, Phila., J. B. Lippincott Co.

Engineering Drawing. Jordan, H. H. and Hoelscher, R. P. 351 pp., 1923, N. Y., John Wiley & Sons.

Introduction to the Study of Alternating Currents. Clayton, Albert E. 296 pp., 1923, N. Y., Longmans, Green & Co.

Prevention of Vibration and Noise. Eason, Alec. B. 163 pp., 1923, Lond., Henry Frowde and Hodder & Stoughton.

Technical Writing. Ed. 2. Rickard, T. A. 337 pp., 1923, N. Y., John Wiley & Sons.



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